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PRACTICAL LESSONS in ELECTRICITY

Selected from the
ELECTRICAL ENGINEERING
COURSE of
AMERICAN SCHOOL of CORRESPONDENCE
at
ARMOUR INSTITUTE of TECHNOLOGY
CHICAGO, ILL.

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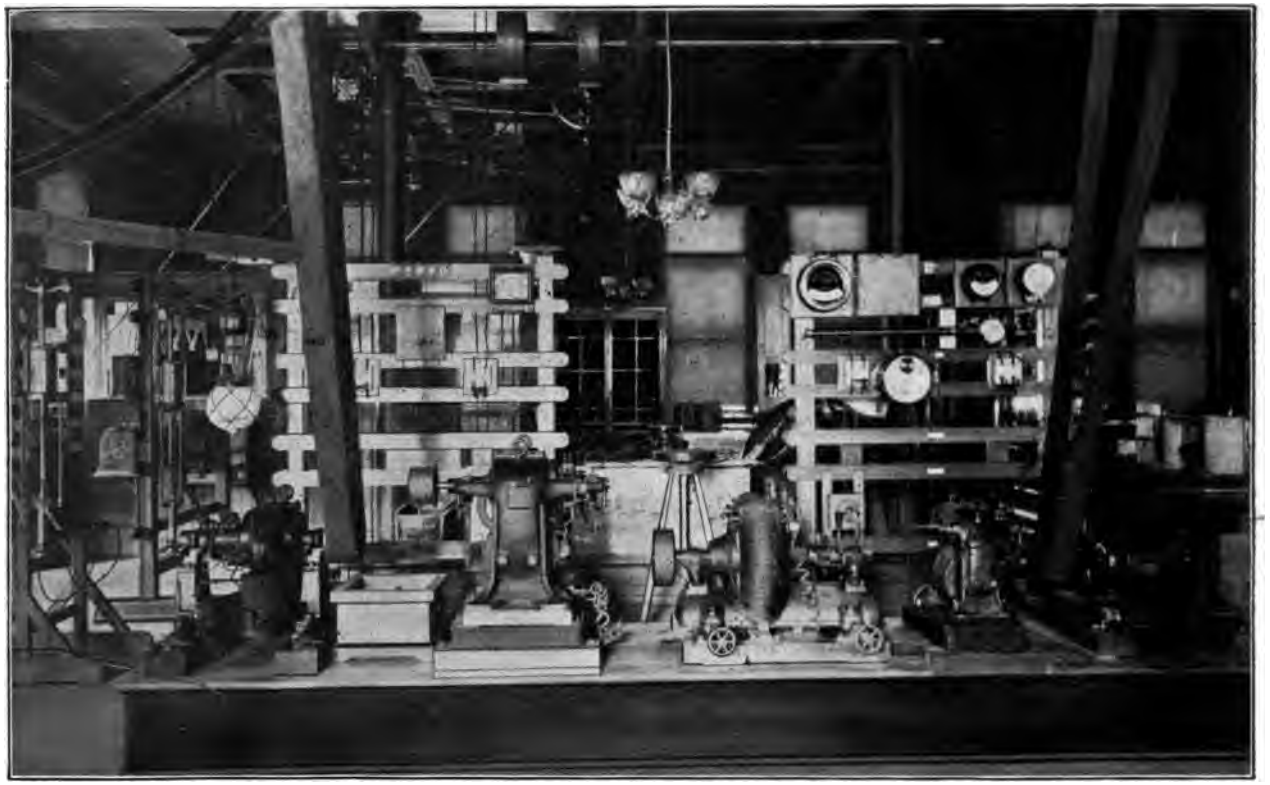

Corner of Electrical Laboratory, Armour Institute of Technology

PRACTICAL LESSONS IN ELECTRICITY

ELEMENTS OF ELECTRICITY
THE ELECTRIC CURRENT

By L. K. SAGER, S. B., LL. B.
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ELECTRIC WIRING

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STORAGE BATTERIES

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Selected from the Textbooks *in the* Electrical Engineering Course *of the* American School of Correspondence *at* Armour Institute of Technology : : : : : : : : : : : : : *Chicago, Illinois*

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THIS VOLUME CONSISTS OF FOUR OF THE FORTY-FIVE REGULAR TEXT-BOOKS IN THE ELECTRICAL ENGINEERING COURSE OF THE AMERICAN SCHOOL OF CORRESPONDENCE AT ARMOUR INSTITUTE OF TECHNOLOGY, BOUND TOGETHER IN CONVENIENT FORM, BUT NOT IN THE ORDER USUALLY STUDIED.

THE PURPOSE OF THE VOLUME IS TO GIVE THE PUBLIC AN OPPORTUNITY TO JUDGE OF BOTH THE STANDARD AND THE SCOPE OF THE INSTRUCTION OFFERED, THE ELEMENTARY INSTRUCTION BEING ILLUSTRATED BY THE FIRST HALF, AND THE ADVANCED INSTRUCTION BY THE LAST HALF, OF THE BOOK.

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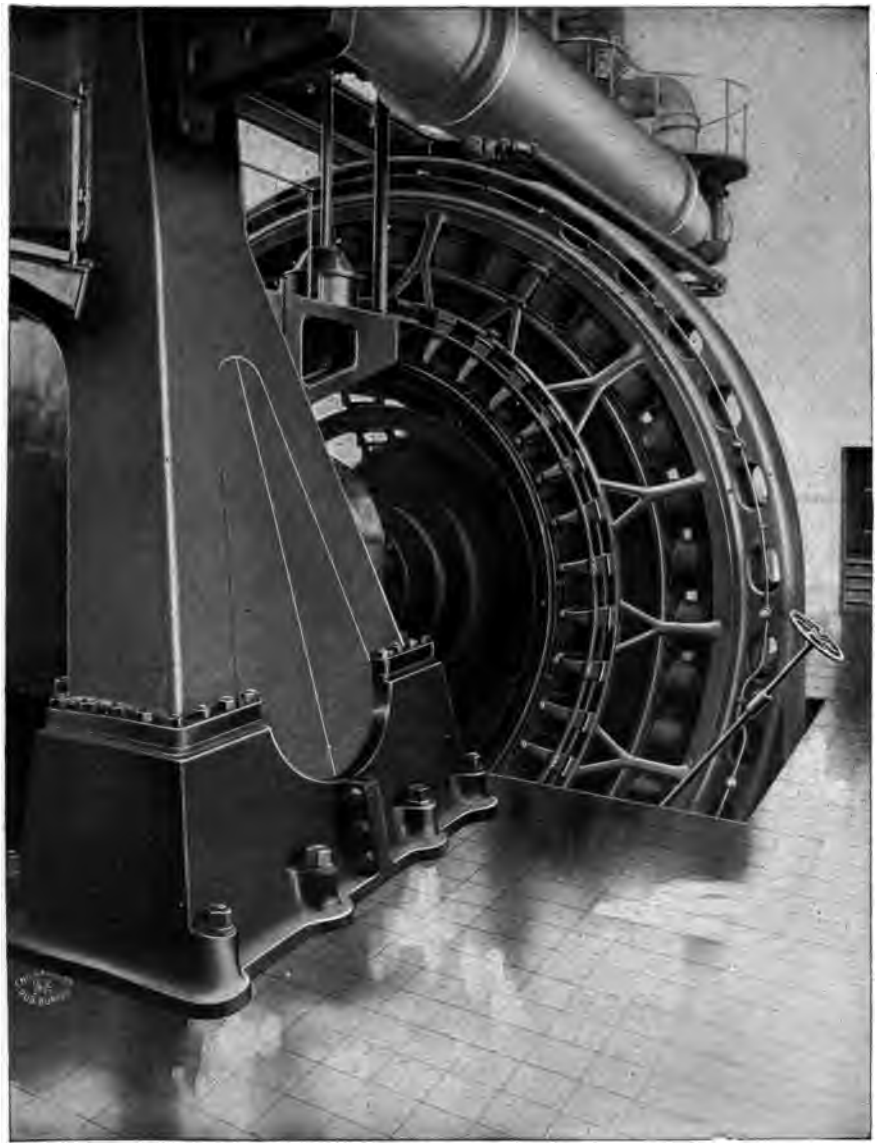

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ELEMENTS OF ELECTRICITY.

Electricity is an invisible agent which manifests itself in various ways. The precise nature of electricity is not known, but the effects produced by it, the methods of controlling it, and the laws governing its action are becoming well known.

Electricity may be considered under three heads: first, **magnetism,** — second, **static** electricity (where it appears as a *charge* upon bodies),— and third, — **dynamic** electricity (where it appears as a *current*). The sciences which treat of the two latter branches are called *electrostatics* and *electrodynamics* respectively. These divisions of the subject, although covering manifestations widely different, are closely related.

MAGNETISM.

Natural Magnets. Substances which have the property of attracting pieces of iron are called *magnets.* A material possessing this property was first found by the Ancients at Magnesia, in Asia Minor, from which fact arose the name *magnet.* The natural magnet is an oxide of iron and is also called the *lodestone.* It is widely distributed in different parts of the world, but is not always found possessing magnetic properties.

Artificial Magnets. When a bar of hard steel is rubbed with a lodestone, the steel will acquire the same magnetic property and to a much greater extent. Such artificial magnets are therefore always used in place of lodestones.

Poles. When one end of a magnet is placed in iron filings and afterwards withdrawn, the filings are attracted and cling to it in great numbers. This is illustrated in Fig. 1. The filings would be attracted to the opposite end and would cling to it in the same way if it were placed in the filings. The middle of the bar, however, does not have this property, and toward the ends the power rapidly increases. The ends of the magnet, where the attraction is the greatest, are called *poles.*

A common example of a magnet is the compass needle. It is well known that such a needle always places itself so as to point

north and south, and that the same pole always points toward the north. This is called the *north seeking pole*, while the other is called the *south seeking pole*, or simply the north and south pole respectively.

In the experiment with iron filings either of the magnetic poles

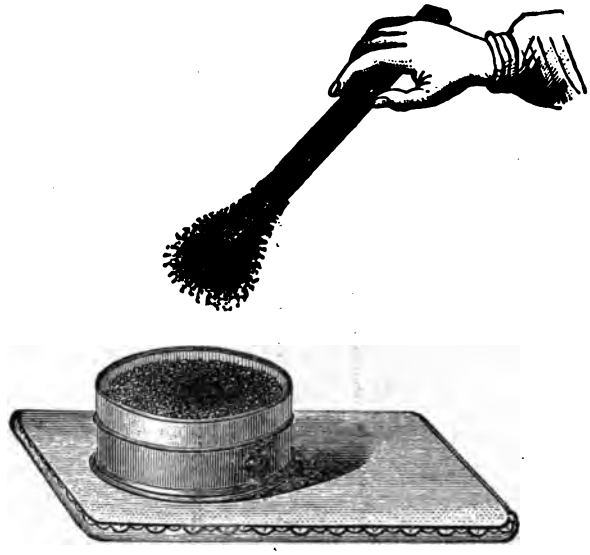

Fig. 1.

attracts them and there is apparently no difference between the two poles. That there is a difference, however, may be shown by experimenting with two compass needles. If the north poles of two such needles be brought near each other, they will be *repelled*. In the same way the south poles will repel each other. But when

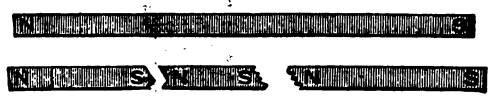

Fig. 2.

the north pole of one needle is brought near the south pole of the other, *attraction* takes place. This shows that *like poles repel* each other, while *unlike poles attract* each other.

The fact that a compass needle always points north and south, or approximately so, is because the earth itself is a great magnet. The magnetic poles of the earth coincide very nearly

with the geographical north and south poles. The geographical north pole of the earth is unlike the north pole of a magnetic needle, and hence attracts it.

The two poles always exist in a magnet. If, as illustrated in Fig. 2, a single magnet be broken into several parts, the separate parts will then become individual magnets. Each portion will have the same properties which the magnet as a whole possessed. When the separate parts are placed together again the many poles of the small portions will neutralize each other and the complete magnet will act as before.

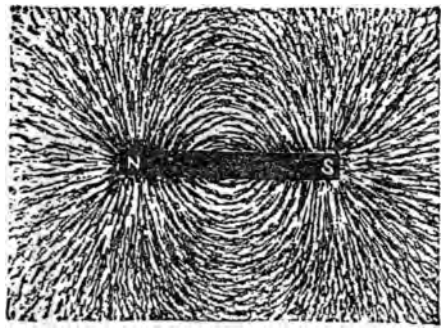

Fig. 3.

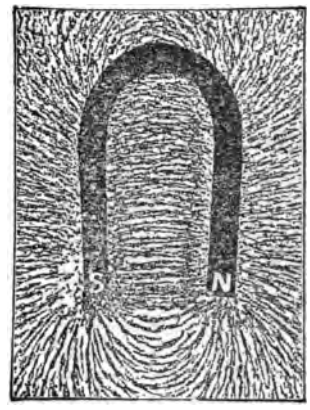

Fig. 4.

Magnetic Field. The space surrounding a magnet, called the field, is subject to the influence of the magnet and is called its *magnetic field.* The presence of such a field may be shown by a simple experiment.

Suppose a sheet of paper be placed upon a bar magnet and iron filings spread evenly upon the paper; by tapping the paper lightly, the filings will form into a series of curved lines extending from one pole to the other. The form of these curves for a bar magnet is illustrated in Fig. 3. The formation of these definite curves indicates that the magnetic field exerts its influence in certain definite directions which are called the *lines of magnetic force*, or simply *lines of force.* The field of a horseshoe magnet is represented in Fig. 4, and that about the end of a bar magnet is represented in Fig. 5.

Magnetic Induction. It is because of this magnetic field that magnets have the power of attracting pieces of iron. When a piece of iron is brought under its influence, it becomes a *temporary* magnet, and for the time being has its two poles. If the north pole of the permanent magnet is adjacent to the piece of iron, a south pole will be induced in the iron next to this north pole and a north pole in the portion farthest from it. The attraction is then exactly similar to the attraction between two permanent magnets when unlike poles are brought together. This action of developing magnetism in iron is called *magnetic induction.*

The attraction of iron is therefore due to the fact that the

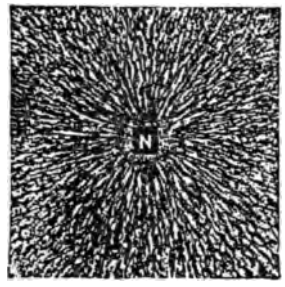

Fig. 5

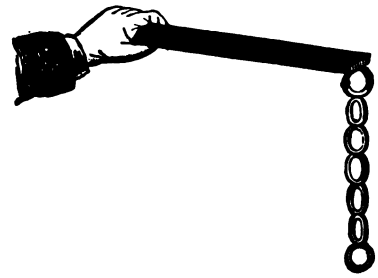

Fig. 6.

magnet first magnetizes it and then attracts it. When the iron is withdrawn from the magnetic influence it loses its magnetism. The experiment illustrated in Fig. 6 proves this to be true. When the upper ring of soft iron is placed in contact with the bar magnet it becomes a magnet, having, say, a north pole at the top and a south pole at the bottom. When another ring is added, the first will in turn induce a north pole at the top and a south pole at the bottom of the second ring. When other rings are added, a similar action takes place and all the rings are supported. If, however, the first ring be removed, the others will immediately drop and will lose their magnetism.

Magnetic induction explains the formation of tufts of iron filings which become attached to the poles of magnets. The filings are temporarily converted into magnets; these act inductively

on the adjacent parts, these again on following ones, and so on, causing them all to be attracted. They have a bush-like appearance, which is due to the repulsive action that the outside free poles exert upon each other.

The attraction is greatest when the iron is in contact with the magnet, but actual contact is unnecessary to cause attraction. A sheet of glass, paper or wood, etc., may be placed between the magnet and the iron, and attraction will still be present.

Magnetic Substances. Substances which are attracted by magnets when either pole is presented to them are called *magnetic substances.* Besides iron are included steel, nickel and cobalt in this class. A magnet is attracted or repelled by another magnet according to whether the poles near each other are unlike or like, but magnetic substances are always attracted.

Retentivity. After a piece of soft iron is once magnetized it will, when removed from the influence of the magnet, lose substantially all of its magnetism. On the other hand, a piece of steel or nickel will not be magnetized as much as soft iron, but will afterwards retain much of its magnetism. It resists being magnetized, and afterwards resists being demagnetized. This power of resisting magnetization or demagnetization is called *retentivity.* Steel has much greater retentivity than wrought iron, and the harder the steel the greater is the retentivity.

Methods of Magnetization. Permanent magnets are usually made from steel, and the following are the common methods of magnetization:

Magnetization by *single touch* consists in moving the pole of a powerful magnet from one end to the other of the bar to be magnetized, and repeating this operation several times, always in the same direction. The end of the bar touched last by the magnet becomes of opposite polarity to the end of the magnet by which it has been touched. This method produces only a weak magnet, and is therefore used for small magnets only.

Magnetization by *divided touch* consists in placing the two unlike poles of two magnets at the middle of the bar to be magnetized, and in moving them simultaneously towards the opposite ends of the bar. Each magnet is then placed in its original posi-

tion and the operation repeated. The bar becomes magnetized after repeating this several times on both faces of the bar.

In magnetization by *double touch* the two magnets are placed as before, with opposite poles near each other, at the middle of the bar to be magnetized. Instead of moving them in opposite directions toward the ends, they are kept at a fixed distance apart by means of a piece of wood between them, and are simultaneously moved first towards one end and then back towards the other, repeating several times and stopping at the middle.

Magnets lose much of their magnetism when subjected to knocks or jars.

STATIC ELECTRICITY.

Friction as a Source. There are several sources of electricity, such as friction, chemical action, heat and induction. Friction as a source of electricity will now be considered. This relates to electricity existing as *charges* upon bodies, and is known as *static electricity.*

When a glass rod or stick of sealing-wax is rubbed with a piece of flannel or silk, each acquires the property of attracting light bodies such as pieces of wool, paper, gold leaf, etc. After coming into contact with such substances, however, they will be repelled. This may be well observed by employing a pith ball suspended by a fine thread, as shown in Fig. 7. When the rod of glass or wax is brought near the ball it is strongly attracted. After contact is made, the ball will be strongly repelled.

This repulsion is explained by the fact that when contact is made between the ball and rod, the ball receives part of the electricity from the rod. Both are then charged with the same kind of electricity, and the repellant action shows that two bodies thus charged, repel each other.

Positive and Negative Electricity. Repulsion does not always take place between bodies charged with electricity. Either a stick of sealing-wax or a glass rod after being rubbed with silk will attract the pith ball until contact has been made, and then will repel it. The electricity developed in each of these cases, however, is not the same. After the pith ball has been touched with an electrified glass rod, it will be *attracted* by the electrified stick of sealing-wax; or if touched by the latter, it

will be repelled by it, but will be *attracted* by the glass rod. Such phenomena are explained by assuming that there are two kinds of electricity, which have been designated as *positive* (+) and *negative* (—) electricity.

When the glass rod is rubbed with silk it is said to possess a positive charge, and when the wax is rubbed it is said to possess a negative charge. The pith ball having been touched by the glass rod is charged positively, and is therefore attracted by the negatively charged sealing-wax, or upon receiving a negative charge from the wax, it will be attracted by the glass.

This action is expressed in the following law:

Electric charges of the *same* sign *repel* each other; those of *opposite* sign *attract* each other.

Production of Both Positive and Negative Electricity. When two substances are rubbed together neither positive nor negative electricity is produced alone, but both are produced at the same time and in equal quantities. After the friction, a positive charge is found to exist upon one surface and a negative charge upon the other and in equal quantities. In the case of glass being rubbed by silk, the glass acquires a positive charge and the silk a negative charge. That the charges are equal is proved by the fact that if both of these charged bodies are presented to the pith ball at once, the latter will be neither attracted nor repelled. Also if the charges of both the glass and silk are imparted to a third body, the third body will have no resultant charge, since the two quantities of electricity being equal and of opposite sign, neutralize each other.

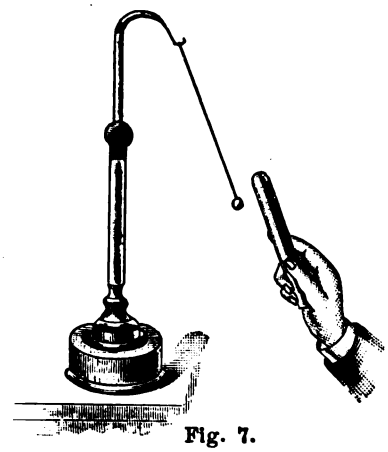

Fig. 7.

Whether a body receives a positive or negative charge depends upon the material of the body with which it makes contact. Thus glass when rubbed by silk is positively charged, but when rubbed by wool the glass is negatively charged. In

following list the arrangement is such that each substance, when rubbed by one following it, will be positively electrified, but when rubbed by one preceding it, will be negatively electrified: Fur, wool, ivory, glass, silk, wood, metals, sealing-wax, sulphur, india-rubber, celluloid.

Conductors and Insulators. *Conductors* are substances which readily allow electricity to pass from one portion of them to another; that is, they readily conduct electricity. *Insulators*, or non-conductors, are those substances which do not allow such free passage of electricity, or which offer a certain *resistance* to its passage. If one end of a glass rod is rubbed with silk or wool, the end so rubbed will be electrified, but the other end will possess little or no charge. The electricity is not freely conducted from one part to another. When a metallic substance is charged, however, the electricity will be distributed uniformly over its surface. All substances offer a certain amount of resistance to the passage of electricity and no body entirely prevents its passage; that is, there is no perfect conductor, and there is no perfect insulator.

There is no definite line of distinction between conductors and insulators, and some substances are neither, but may be termed semi-conductors or partial conductors. The ability of a body to conduct electricity, that is, its *conductivity*, also depends upon its physical condition. For example, the conductivity of most bodies depends largely upon the temperature. The following list of substances is arranged in the order of increasing resistance.

Conductors.	*Partial Conductors.*	*Insulators.*
Silver	Cotton	Oils
Copper	Dry wood	Porcelain
Other metals	Marble	Wool
Charcoal	Paper	Silk
Water		Resin
The body		Guttapercha
		Shellac
		Ebonite
		Paraffin
		Glass
		Air

From the preceding it is evident that silver is the best conductor and air is the best insulator. Copper, on account of being an excellent conductor and comparatively cheap, is used almost entirely for conducting electricity from power stations or from one point to another. Marble is a comparatively poor conductor and is therefore largely used for switchboards. Porcelain and glass, being good insulators and having other desirable properties are much used for insulating conductors from their main supports. Water is a fairly good conductor, and considerable difficulty is consequently experienced in securing good insulation in damp places.

Distribution of Charge. An electrical charge upon a conducting body is distributed over its *surface*. That it does not reside *within* the body may be shown in several different ways. For example, it is immaterial whether the inside of a conductor is composed of wood or glass, or if the conductor is hollow; the charge in any case is distributed over its surface.

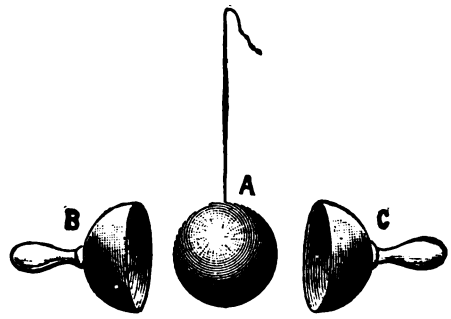

Fig. 8.

The ball *A* and covers *B* and *C*, shown in Fig. 8, may be used to prove this. Suppose the covers to be placed over the ball and the whole to be electrified. When the covers are removed, the entire charge will be found to remain with them, and none will exist upon the ball.

Suppose the hollow sphere in Fig. 9 to be charged. If a conductor be inserted through the aperture and brought in contact with the inside of the sphere and afterwards carefully withdrawn, it will be found that it has received no charge. If touched to the outside, however, the conductor will receive part of the charge. The conductor used for this purpose may be a thin piece of metal attached to an insulating handle. A metallic cylinder, even of wire gauze, may be used in place of the sphere. To prevent the charge from passing to the earth, the cylinder or sphere must be insulated from the earth by a glass standard.

We have seen that bodies charged with electricity of like sign repel each other. This may be taken as the explanation of the fact that a charge resides upon the surface. As it tends to repel itself, the charge resides as far from the centre of the body as possible.

Static Influence. When a charged body is placed near bodies in a neutral state, it will act upon them in a manner similar to that of a magnet upon soft iron. This action is said to be due to influence or to *electrostatic induction.*

Induction of this nature may be made evident by means of a metal cylinder supported on a glass standard, as shown in Fig. 10. The cylinder is supplied at each end with a pith ball suspended by a thread. Suppose a sphere charged with positive electricity and mounted upon an insulating standard be brought near one end of the cylinder; the pith balls will at once fly outwardly, showing that the cylinder is then charged. If the sphere is removed, the pith balls will fall towards the ends of the cylinder again, showing that it is once more in the neutral state. Throughout this action the sphere has neither gained nor lost in the amount of its charge. Upon testing the temporary charge on the cylinder, it will be found that at the end near the sphere the electricity is negative while that at the distant end is positive.

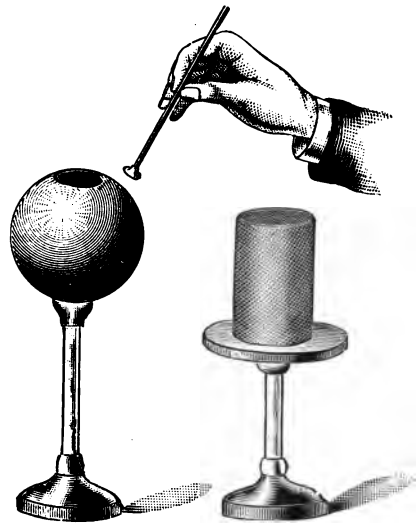

Fig. 9.

Bodies charged with electricity are surrounded by an electric field in the same way that magnets are surrounded by a magnetic field. With this in mind, the above experiment may be easily understood. When the charged sphere is brought near the cylinder, the latter comes under the influence of the former's field. The lines of force from the sphere will pass to the cylinder, and therefore cause its electrification. Since unlike charges attract

each other and like charges repel each other, the sphere attracts a negative charge to the near end and repels a positive charge to the distant end of the cylinder. When the sphere is removed, the induced positive and negative charges neutralize each other. If the sphere possessed a negative charge, there would then be induced a positive charge at the near end and a negative charge at the distant end of the cylinder. The middle portion of the cylinder, however, remains neutral, and the strength of the charges increases gradually towards the ends. If the cylinder be separated into two parts while under the influence of the charged body, the induced charges cannot unite after the removal of the sphere, and will then retain their charges.

In the experiment illustrated by Fig. 10, there is consider-

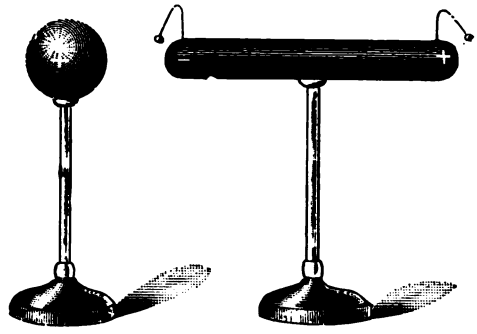

Fig. 10.

able attraction exerted between the sphere and cylinder. The unlike and adjacent charges attract each other, but the like charges on the sphere and distant end of the cylinder repel each other. As the unlike charges are nearer each other than the like charges, the attraction overbalances the repulsion and there is a resultant attraction. This action is the same in effect as that of magnets upon soft iron. There is first the induction and then the consequent attraction.

The greater the charge possessed by the sphere, the greater will be the induced charge upon the cylinder. Also, the nearer the two bodies are placed to each other, the greater becomes the charge upon the cylinder, but the induced charge can never exceed that on the sphere.

When the distance between the sphere and cylinder is great

ually decreased, the attraction between the unlike charges is increased. This will continue until the attraction is so great that the unlike charges abruptly unite, and in so doing cause a spark to appear in the small intervening space. The unlike charges are thus neutralized, but the repelled charge will still remain upon the cylinder.

Free and Bound Charge. The two charges induced in the cylinder may be called free and bound charges. The unlike induced charge, which is represented as negative in Fig. 10, is referred to as the bound charge, because it is attracted by the charge upon the sphere and is thus confined. The repelled charge, however, may escape by any path which is offered, and is therefore called the free charge. Hence if contact be made between the cylinder and the earth, the repelled charge will pass to the ground and the attracted charge will remain. If the contact with the earth is then broken and the sphere removed, a resultant charge will remain upon the cylinder, which will be opposite in kind to that of the sphere. This resultant induced charge will then distribute itself uniformly over the cylinder and may be used to induce other charges.

Fig. 11.

When bodies are thus charged by induction, the charge is always opposite in kind to that inducing it. On the other hand, when bodies are charged by conduction or by making direct contact, the charge imparted is of the same kind. Poor conductors are not readily acted upon by induction, since they present great resistance to the passage of electricity.

Electroscope. An electroscope is an instrument used for detecting the presence and determining the kind of electricity in any body. The gold-leaf electroscope shown in Fig. 11 is one of the common forms, and is a very sensitive instrument. It

consists of a glass jar with a metal rod passing through the stopper and terminating at the lower end in two strips of gold leaf, and at the upper end in a metal plate or knob.

When a charged body is brought near the plate, an unlike charge is induced therein, while a like charge is repelled to the two strips of gold leaf. The two strips, being then similarly charged, repel each other and diverge. When the charged body is withdrawn, the strips will come together again. A rubbed glass rod will cause the strips to diverge even when two or three feet from the plate.

In order to determine the kind of electrification a body possesses, the plate is first touched by a body charged with a known kind of electricity, say positive. The electroscope is then charged with positive electricity and the strips of gold diverge. The body to be tested is then brought near the plate. If the gold leaves then diverge more, the body is charged with positive electricity, but if they approach each other, the body is charged with negative electricity.

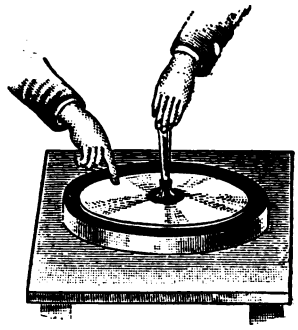

Fig. 12.

Electrophorus. This is an apparatus by which an unlimited number of charges may be obtained from a single charge. It consists of a round cake of resinous material (Fig. 12), formed in a shallow metal pan, and a round metal plate of slightly smaller diameter, provided with a glass handle. In using the electrophorus, the resin is first rubbed with a woolen cloth or with a cat's skin, and receives a charge of negative electricity. The plate is then placed on the cake. Owing, however, to the unevenness of the resin, the plate comes in contact with only a few points, and on account of the non-conductivity of the resin the negative electricity of the cake does not pass to the plate. On the contrary, it acts by induction on the plate and attracts a positive charge to the under surface and repels a negative charge to the upper. The plate is now touched with the finger, and the induced negative electricity being repelled and free to pass off. The plate then retains a bound charge of positive elec-

H, which extend one on each side of the plate. These arms carry teeth in the form of combs which extend inwardly, but are not in contact with the plate. Electricity tends to escape from sharp or pointed projections, and round, polished surfaces are best adapted to retain a charge. A silk flap *S* is attached to the cushions and partially covers the plate.

When the handle is turned, the frictional contact causes the rubber to be negatively electrified and the plate positively. The positive charge is carried around on the plate and acts inductively upon the prime conductor *G*, repelling a positive charge to its distant end and attracting a negative charge. The negative electricity, being attracted by the positive charge on the plate, passes readily to it by means of the combs *H*, and these charges are thereby neutralized. Hence that portion of the plate which has passed the combs retains no charge, but an induced, positive charge accumulates on the conductor *G*. Upon passing the cushions, that portion of the plate is recharged, and the action is repeated. The lower half of the plate is therefore always charged, and the other half is neutral. As each successive part of the plate passes the cushion it receives a positive charge, which is neutralized when it passes the combs. The flap *S* is used to reduce electrical leakage from the plate. When positive electricity is to be collected on *G*, conductor *E* is put in connection with the earth by means of a chain or wire, *F*. The negative electricity of the cushions is thereby neutralized. Negative electricity may be collected upon conductor *E*, by connecting *G* to ground instead of conductor *E*.

Condensers. A condenser is an apparatus for accumulating a large quantity of electricity on a comparatively small surface. The form may vary considerably, but in all cases it consists essentially of two conductors separated by a non-conductor, and its action depends upon induction.

In explaining the action of the condenser, the apparatus illustrated in Fig. 14 will be considered. The two plates *A* and *B* are insulated conductors, and *C* is a glass plate between them. Each of the conductors has a pith ball *a* and *b* connected with it. Let plate *A* at first be at such a distance from *B* as to be out of its sphere of influence. The plate *B* is then connected by the

conductor x, to the positive conductor of an electrical machine, and receives a positive charge, which is distributed uniformly over its surface. The pith ball or pendulum b will diverge widely, and if connection with the charging machine then be broken, no change in the distribution of the electricity occurs. However, when plate A is placed in the position shown, the distribution is considerably changed. This plate is connected to the earth by a conductor y. The positive charge on B now acts inductively across the intervening space and glass-plate C, repelling a positive charge to the earth through y, and attracting a negative charge which resides on the face n of plate A. This negative charge now reacts upon the positive of plate B and attracts it. The uniform distribution on this plate is then disturbed and the positive electricity accumulates on the face m of plate B. That the density of charge on the other portions of conductor B is diminished, is shown by the fact that pendulum b diverges less. Owing to there being less electricity on portions of B than before, B can be recharged until the pendulum diverges as much as at first. The

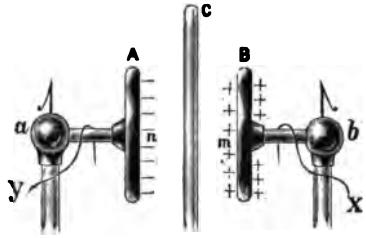

Fig. 14.

effect of plate A, therefore, is to condense the electricity on face m of plate B and thus increase its capacity for more electricity. Electricity is then distributed over the entire surface of B, but is much more dense on face m. If the connections x and y be broken and the plates separated so that they have no effect upon each other, the positive charge will then be distributed equally over the surface of B, and the negative charge equally over surface A. This is shown by the pendulums diverging much more than before.

The nearer the plates A and B are to each other, and the greater their size, the greater the capacity of the apparatus; that is, the greater may be the charge on B.

Leyden Jar. The Leyden jar is the most convenient form of condenser. It consists, as shown in Fig. 15, of a glass jar, coated within and without for about two-thirds of its height with tin foil. The stopper has a metallic rod passing through it which communicates with the inner coating by means of a small chain. The upper end of the rod terminates in a knob. The upper portion of the jar, the stopper and the supporting rod are usually coated with shellac to protect them from moisture. The inner coating corresponds to the collecting plate *B* of Fig. 14, the glass to the insulating plate *C* and the outer coating to the condensing plate *A*.

The jar is charged by holding the knob to the prime conductor of an electrical machine or other source of electricity, and connecting the outer coating to the earth by a wire or chain, or by holding the jar in the hand. When the knob is presented to the positive conductor of the machine, positive electricity is accumulated on the inner coating and negative electricity on the outer coating. The positive charge acts inductively through the glass and repels a positive charge to the earth and attracts a negative charge on the inner face of the outer coating. The action of the jar is therefore the same as that of the condenser previously considered.

Fig. 15.

The jar should be made of good glass, should be kept dry and free from dust. The thinner the glass the greater is the capacity, but if the glass is too thin it will not be effective in insulating the charges from each other. In such a case a spark will pass from one coating to the other directly through the glass.

The jar may be discharged by connecting the inner and outer coatings by a conductor. If the outer coating be held in one hand, and the other hand be presented to the knob the person will experience a severe shock, as the arms and body then provide a path for the electricity to unite. To eliminate danger in discharging, a pair of discharging tongs should be used. These consist of jointed brass rods provided with knobs at the separable ends and also provided with insulating handles. One of the knobs is brought in contact with the outer coating and the other

brought near the knob connected to the inner coating. A bright spark then leaps between these two knobs and the discharge is accomplished.

For the accumulation of powerful charges, a *battery* of jars is used. This consists of several jars, which have all the inner coatings or knobs connected together and all the outer coatings connected together. The battery is charged and discharged in the same manner as a single jar; in fact, the battery is equivalent to a single jar having very large inner and outer coatings. Great care must be taken in charging or discharging a battery, as a shock received may be serious enough to prove fatal.

DYNAMIC ELECTRICITY.

Dynamic electricity or electrodynamics, considers the flow of electricity in *currents*. In the preceding pages the static charge has been considered, but it has been shown that such a charge may pass readily from one conducting body to another when a suitable path is provided. If electricity could be supplied just as fast as it flowed away, there would be a continuous flow, or current of electricity. Hence if one end of a wire is kept positive and the other negative, electricity constantly flows from one end to the other. This result may be obtained by chemical action, heat or induction. The latter method, which includes the movement of wires across a magnetic field, is used in the dynamo and is fully considered in following Instruction Papers. In all cases when a continuous current flows there must be a complete circuit provided.

Voltaic Cell. A continuous current is obtained from the voltaic cell, and the source of the electricity is the chemical action. Such a cell is illustrated in Fig. 16. The glass jar *A* contains dilute sulphuric acid, in which are placed the copper plate *C* and the zinc plate *Z*. When a wire connects the two plates, as shown, a continuous flow of electricity takes place (as indicated by the arrows) from the copper plate through the wire to the zinc plate and through the liquid to the copper plate. The flow of current tends to neutralize the difference in electrical condition of the plates, but the chemical action within the jar maintains this difference. This electrical difference between the plates is called the *potential* difference; and the greater the amount of

potential difference, the greater is said to be the *pressure, electromotive force* or *voltage*, which causes a current to flow. The strength of the current passing depends directly upon the amount of this electromotive force. The current strength also depends upon the amount of *resistance* to its flow. If the circuit is short and made up of good conductors, the current will be much stronger than if it were long and made up of poor conductors.

Flow of Electricity. Electricity, although commonly described and referred to as *flowing* through a circuit does not actually *flow*. There is no transfer of matter along the circuit. A wire carrying a current looks the same as one that is not, and that electricity is present is only evident by the heating, chemical or magnetic effects produced. It is convenient, however, to describe electricity as flowing, and this term suffices for all practical purposes.

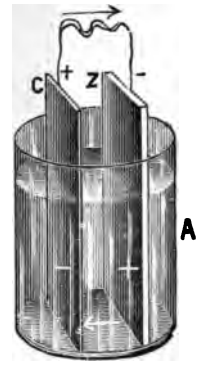

Fig. 16.

In order to show the relation between electromotive force, current and resistance, electricity flowing in a circuit is often compared to the flow of water in a pipe which connects two reservoirs containing water at different levels. When a clear path is provided, the water will flow from the reservoir at the higher level to the one at the lower level, and the greater the difference in the levels the greater is the pressure and consequent flow of water. Also the water will flow much faster through a short large pipe, than through a long and small one. Similarly, the greater the pressure or electromotive force the stronger is the current of electricity, and the greater the resistance of the circuit the less the current. This analogy must not be too closely applied, however, for the reason that with water there is an actual transfer of matter.

Internal and External Resistance. The circuit shown in Fig. 16 may be divided into two parts,—the *internal*, which includes the plates and liquid, and the *external* circuit which consists of the wire connecting the plates. If this wire is small and long, it will have a high resistance and only a weak current will flow. The resistance of liquids as compared with metals is con-

siderable. The internal resistance of a cell may be reduced by having the plates large and putting them close together. Gases are poor conductors of electricity, and hence the bubbles caused by the chemical action and which cling to the plates, greatly increase the internal resistance.

Fig. 17.

Fig. 18.

Chemical Action in the Cell. The essential elements of a voltaic cell are: a plate, which may be oxidized, such as zinc, a liquid capable of acting on this plate, such as sulphuric acid, and an inactive plate, such as copper. When the wire connecting the plates is broken, there is no current, but upon closing the circuit chemical action takes place and a current flows. The chemical reaction which occurs is represented as follows:

$$Zn + H_2SO_4 = ZnSO_4 + H_2,$$

which is equivalent to saying that the zinc (Zn) combining with the sulphuric acid (H_2SO_4), produces zinc sulphate ($ZnSO_4$) and free hydrogen gas (H_2). The hydrogen is given off as a gas from the liquid and zinc sulphate remains in solution. This action takes place as long as the current flows and depends upon the amount of current flowing. The zinc gradually dissolves into the liquid and the latter gradually becomes a solution of zinc sulphate. When the liquid no longer contains any acid or when the zinc is used up, the chemical action ceases. The spent liquid must then be replaced by a new acid solution and a new piece of zinc substituted.

Polarization. One great objection to the simple voltaic cell is that the current produced, rapidly decreases in strength after the circuit is closed for a short time. This is due mainly to the collection of hydrogen bubbles upon the surface of the copper plate. This coating of bubbles hinders the direct contact of the copper plate with the liquid as its effective area is reduced. This also greatly increases the internal resistance of the battery.

When this accumulation of hydrogen bubbles takes place, the cell is said to be polarized. In order to reduce this action and so enable a cell to maintain a constant current for some time, single fluid cells have been largely replaced by double fluid cells. In these the inactive plate, about which the bubbles would otherwise collect, is placed in a liquid which chemically unites with the hydrogen.

Among the numerous forms of cells now manufactured, the following are described as being among the most important.

Smee's Cell. In this cell, which is illustrated in Fig. 17, polarization is reduced by mechanical means. The cell consists of a silver plate, coated with a deposit of finely divided platinum, and suspended between two zinc plates in dilute sulphuric acid. The middle plate has a roughened surface due to the deposit of platinum, and the hydrogen bubbles therefore readily disengage from its surface and pass off.

Bichromate Cell. This cell, shown in Fig. 18, has the zinc plate suspended between two carbon plates which are joined together at the top. The solution used is made up of dilute sulphuric acid and bichromate of potash. The latter substance chemically unites with the free hydrogen and so prevents polarization. This solution also attacks the zinc, even when the circuit is open, and when not in use the zinc plate is raised above the solution by the rod *A*.

Leclanche Cell. In place of the sulphuric acid solution, this cell is provided with a solution of ammonium chloride (sal-ammoniac), in which a zinc rod is placed. Within the jar containing this solution is placed a porous cup, as shown in Fig. 19. This contains a rod of carbon, which is the inactive element, and closely packed about it is black oxide of manganese and powdered carbon. The oxide slowly gives off oxygen and so prevents

accumulation of hydrogen about the carbon. The porous cup, although it does not interfere with the passage of the current, protects the zinc from the action of the oxide. This cell is much used in connection with telephones and electric bells, or where it is desired to use it for only a few minutes at a time. If used for a long period, the current strength decreases, but quickly regains its original power when the current is interrupted. It is therefore well adapted for intermittent service.

Daniell Cell. The Daniell cell (Fig. 20) is made up of an outer portion of copper, which serves as the inactive element. Within this is a saturated solution of copper sulphate, and crystals

Fig. 19.

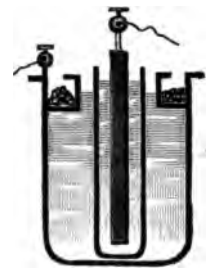

Fig. 20.

of copper sulphate are provided in perforated cups at the top, so that they may dissolve and keep the solution saturated. A porous cup containing dilute sulphuric acid or zinc sulphate and a rod of zinc, completes the cell. The porous cup protects the zinc from the copper sulphate solution, and this solution prevents the hydrogen from accumulating about the copper. The hydrogen unites chemically with the copper sulphate forming sulphuric acid and free copper. The free copper is then deposited upon the outside copper portion. The action is represented as follows:

$$H_2 + CuSO_4 = H_2SO_4 + Cu,$$

which is equivalent to saying that hydrogen united with copper sulphate produces sulphuric acid and copper.

This cell is very constant in its action because, as long as the copper sulphate solution is saturated, no polarization can take place. This cell is much used in telegraphy, and is kept on a closed circuit, the interruption of the circuit being used to give the signals, instead of the closing of the circuit.

Grove Cell. In the Grove cell (Fig. 21) a hollow cylinder of zinc is placed in dilute sulphuric acid. Within this cylinder is a porous cup containing strong nitric acid and a strip of platinum for the inactive element. Polarization is prevented by the hydrogen uniting with the nitric acid. This cell has a low internal resistance and can produce a strong current for several hours.

Bunsen Cell. This is similar to the Grove cell, except that the platinum is replaced by a rod of carbon (Fig. 22). It has a slightly higher electromotive force than the Grove cell and is less expensive, but it has higher internal resistance.

Fig. 21.

Fig. 22.

Gravity Cell. Where one of the two liquids used in a cell is heavier than the other, their difference in specific gravity may be depended upon to keep the liquids separate, instead of using a porous cup. The heavier liquid then remains at the bottom of the cell and the lighter one forms a layer above it. Fig. 23 shows such a cell, which is the same as the Daniell cell except that no porous cup is used. A copper plate at the bottom is surrounded by crystals of copper sulphate and covered with a solution of the same. The zinc is supported above this and in a dilute solution of sulphuric acid or zinc sulphate. The copper sulphate solution being the heavier remains at the bottom and prevents polarization. The two solutions do not remain entirely separated, however, as the heavier solution slowly diffuses upward.

Dry Cell. In this cell, which is more properly called a *moist* cell, the usual liquid solutions are dispensed with, and in place of them the cell is provided with substances capable of retaining

moisture for a long time. These cells have the advantage of being very conveniently handled and are extensively used. One form of dry cell is shown in Fig. 24. In this cell the usual glass jar is replaced by a zinc tube or cup, to which a clamping screw is attached. Within this is a carbon rod forming the inactive plate and also provided with a clamping screw. The zinc is lined with a compound corresponding to the acid solution of other cells, and the carbon is surrounded by a semi-solid compound which acts to prevent polarization. After the ingredients have been placed in the cell, it is sealed at the top with bitumen or other similar substances.

MAGNETIC EFFECTS OF ELECTRIC CURRENT.

On the preceding pages magnetism, static charges of electricity and the electric current have been considered. It has been shown that static charges act very much like magnets in regard to attraction, repulsion, induction, etc.; but no connection between magnets and charges of electricity has yet been discovered. A static charge, either positive or negative, has the same effect upon the north pole of a magnet as upon the south pole. There is, however, a close relation between magnetism and the electric current.

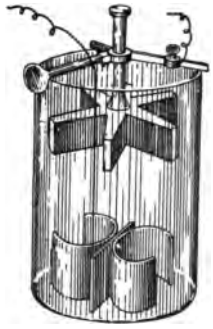

Fig. 23.

Deflection of the Magnetic Needle. We have seen that when a conductor connects two materials having a difference of potential between them, that a current will flow as soon as the circuit is completed. This current causes the wire to be surrounded by a magnetic field, and the magnetic field consists of lines of force which encircle the conductor. The field is strongest near the conductor and diminishes gradually in strength at increasing distances therefrom. The presence of this magnetic field may be shown by the experiment illustrated in Fig. 25. When the pivotally supported magnet having poles N and S is placed near the wire carrying a current, the needle will be deflected and tend to place itself at right angles to the wire. The direction in which the needle is deflected will depend upon the direction of the

current, and whether the needle is above or below the wire. The amount of the deflection will depend mainly upon the current strength, length of the magnet and strength of its poles. This phenomenon is made use of in measuring the strength of currents, and is one of the fundamental principles of electrical measuring instruments.

Fig. 24.

Solenoid. When an electric current is passed through a coil of wire such as is shown in Fig. 26, the coil becomes equivalent to a magnet, and has poles *N* and *S* as indicated. Such a coil is called a solenoid. The magnetic field surrounding each turn of wire unites to form a magnetic field about the coil similar to that of a bar magnet, as shown in Fig. 3. If free to turn, the solenoid assumes a position such that its axis will point north and south, and thus acts like a compass needle. The same phenomena of attraction and repulsion exist between solenoids, or between solenoids and magnets, as exist between magnets. Which end of the solenoid becomes the north pole and which the south, depends upon the direction of the current through the coil.

Electromagnets. Since a solenoid is surrounded by a magnetic field similar to that of a magnet, it follows that the solenoid is capable of magnetizing pieces of soft iron and attracting them in the same way as does a steel magnet. The field of a solenoid is strongest within its windings, and it follows that if a bar of soft iron is placed within the coil, the bar will be much more strongly magnetized than if placed in any other position about the coil. A coil adapted to carry a current and provided with a soft iron core is called an *electromagnet*. In order to permit the wire to be closely wound and at the same time force the current through each turn, the wire is covered with insulation throughout its length. Such insulation may consist of a covering of silk, cotton or guttapercha. The core remains a magnet only while the current is flowing.

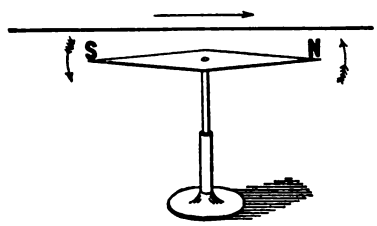

Fig. 25.

Electromagnets may be made very powerful, and when made in the form of a horseshoe have great lifting power. A horseshoe electromagnet is shown in Fig. 27. The winding of the two coils *A* and *B* must be such that the ends of the horseshoe have opposite polarity. This condition is fulfilled if the winding

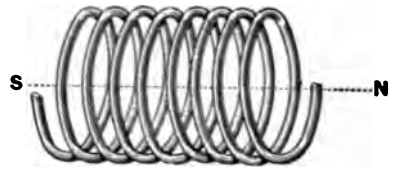

Fig. 26.

on the two links is in the same direction, when the horseshoe is straightened out.

Applications of Electromagnets. The great advantage in using the electromagnet lies in the control of its magnetism. When the current is passing, the core is strongly magnetized, and when no current flows it ceases to act as a magnet. Hence its action may be controlled by simply opening or closing the circuit by a key or switch, the source of the electricity being included in the circuit. This control of the magnet may be accomplished at great distances by merely extending the wires from the coil to the distant point and operating the switch or key at that point.

Fig. 27.

Telegraphic instruments are constructed upon this principle, the closing of a key at a distant point causing the electromagnet to attract a piece of iron called its armature, supported near its poles, and so give a signal. When the current ceases to flow, the armature is forced away from the poles by the action of a spring, the force of the spring being overcome, however, whenever the current passes.

The electromagnet is also used in electric bells. The armature carries a hammer which strikes against the bell whenever the armature is attracted. By the rapid opening and closing of the circuit, which is accomplished automatically, the hammer is made

These induced currents are caused by the field surrounding the magnet moving or cutting across the wires composing the coil. If a current were passed through the coil, it would create a magnetic field, so on the other hand, the movement of a magnetic field within the coil produces a current. It makes no difference whether the magnet or the coil is moved, so long as there is relative movement. This production of a current by the relative movement of a magnetic field and a conductor, is the fundamental principle of all dynamos.

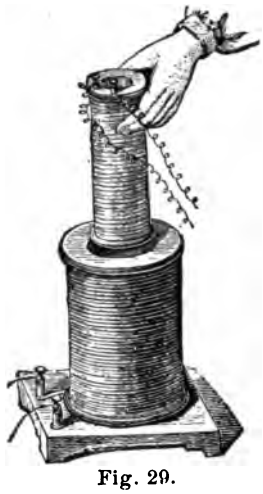

Fig. 29.

Induction by Currents. As a solenoid is surrounded by a magnetic field similar to that of a bar magnet, it follows that if a solenoid carrying a current were thrust within another coil, induced currents would be produced in the latter. This experiment is illustrated in Fig. 29. These induced currents, as in the case when the magnet is used, only flow during the motion of the solenoid. When the solenoid is inserted, the induced current flows in one direction and when withdrawn, it flows in the opposite direction. The insertion of the solenoid induces a current which has a direction opposite to that in the solenoid, and the withdrawal induces a current which has the same direction as that in the solenoid.

Induction Coil. Suppose now that the two coils shown in Fig. 29 are placed one within the other, there being no current passing, and that a current is afterwards passed through the inner coil. Upon permitting the passage of a current in the inner coil a momentary current is induced in the outer coil, the same as if a magnet had been thrust into the coil. This induced current continues, however, only while the current in the inner coil is increasing in value from zero to its normal amount. As soon as this normal strength is reached the induced current ceases to flow. Now when the circuit of the inner coil is broken and its current ceases to flow, another momentary current is induced in the outer coil, which has a direction opposite to that formerly passed

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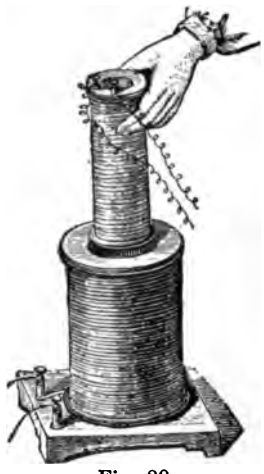

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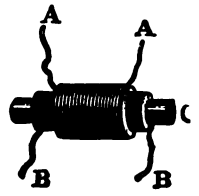
through it. Such an instrument for producing induced currents is called an *induction coil.* The coil through which the original current is passed is called the *primary* coil, and that in which the currents are induced is called the *secondary* coil. The induction coil is the fundamental principle of transformers, commonly used in long distance power transmission.

Fig. 30 illustrates an induction coil having the two sets of windings *A* and *B* and also supplied with a soft iron core *C*. This iron core greatly increases the amount of induction.

The production of induced currents by opening and closing, or making and breaking the primary circuit, is similar in action to thrusting a magnet within and withdrawing it from a coil. When a magnet is used, the induction is caused by the magnetic



A is secondary coil.
B is primary coil.

Fig. 30.

field moving across the wire composing the coil. Now when the primary circuit is closed, a magnetic field is created, which is equivalent to thrusting a magnet within the coil. The breaking of the primary circuit is equivalent to withdrawing the magnet, and so induces a current. The current induced by closing the primary circuit is *opposite* in direction to that of the primary current, and that induced by breaking the primary circuit is in the *same* direction as the primary current. The induced currents are only caused by the changing in strength of the magnetic field surrounding the secondary circuit. Therefore, while a constant current is passing in the primary circuit, there will be no induced currents. When the strength of the primary current changes, however, secondary currents will be induced. The strength of these induced currents will depend upon the abruptness of change in the primary current, and their direction will depend upon whether the primary current increases or decreases.

It should be remembered that before a current can flow there

must be a closed circuit, and an electromotive force. A current flows in the secondary circuit only when it is closed, but the electromotive force exists whether or not the secondary circuit is closed. Strictly speaking the electromotive force is first produced or generated, and the current then flows when the circuit is closed. The value of the electromotive force generated in the secondary, depends upon the number of turns in the same; a much higher electromotive force being generated in a coil of a large number of turns than in a coil of a few turns. This fact is of great practical importance, for it thus provides a means of obtaining very high electromotive forces.

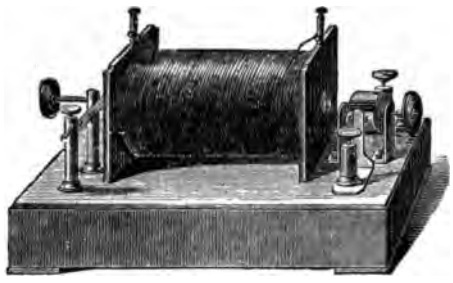


Fig. 31.

Fig. 31 illustrates an induction coil arranged to generate a very high electromotive force, and for producing sparks between widely separated points. The primary coil consists of a few turns of coarse wire, and about this is the secondary coil made up of many thousand turns of fine wire, all of which are well insulated. In the primary circuit are connected a few Grove's or Bunsen's cells and a switch for interrupting the circuit. The making and breaking of the primary circuit generates a very high electromotive force in the secondary. Sparks of considerable length may be produced between the terminals of the secondary by this type of coil. A condenser is used in connection with the device, in order to decrease the electromotive force induced by closing the primary circuit, and to increase that induced by opening the primary circuit. The sparking therefore occurs at the breaking of the primary circuit. A powerful induction coil made at London, in which the secondary coil contained 280 miles of wire wound in 340,000 turns, yields a spark $42\frac{1}{2}$ inches in length, when worked by 30 Grove's cells.

Mutual and Self-Induction. Induction produced in one conductor by currents in another, which has no electrical connection with the first, is called *mutual* induction. We have seen

that mutual induction is caused by the change in strength of the magnetic field surrounding the secondary coil. The primary coil must necessarily be subject to the same change in field strength, which is therefore acted upon inductively as well as the secondary coil. This reaction tends to oppose any increase or decrease in the primary current. It is greater for a coil having a large number of turns or one provided with an iron core. This inductive action of a coil upon itself is called *self-induction.* Electromagnets have very high self-induction. Upon closing the circuit in such a coil its self-induction causes the current to increase in strength very slowly, and upon opening the circuit self-induction tends to prolong the current, and produces what is termed an "extra current." The high electromotive force causing this extra current, may be sufficient to give a dangerous shock, and produces a bright spark where the circuit is opened.

HEATING EFFECTS OF CURRENT.

Heating Depends upon Resistance. We have seen that some substances are very good conductors of electricity, that others are fairly good and that others are very poor conductors. That is, some substances offer very much more resistance to the flow of electricity than others. In order to force the current through this resistance, a certain amount of energy must be expended and the greater the resistance, the greater is the amount of energy required. The energy which is thus consumed, appears in the form of heat. From every part of a circuit through which a current is flowing, heat is dissipated, and this heating raises the temperature of the circuit a certain amount. A short, stout copper wire has low resistance, and so causes but little heat to be generated. Also on account of its large radiating surface, this heat is readily given off to the surrounding air, and therefore its temperature is raised only to a small extent. A fine platinum wire, however, has high resistance and but small radiating surface, hence if the same current be passed through this wire, it will come to a high temperature and may even become incandescent.

The laws of heating in electrical circuits were first formulated by Joule. Joule's law is as follows:

The number of heat units developed in a conductor is propor-

tional to its resistance, to the square of the current, and to the time that the current lasts.

The amount of heat developed therefore increases in direct proportion to the resistance, but increases as the *square* of the current. Hence doubling the resistance, doubles the heat generated, if the current remains the same, but doubling the current increases the generation of heat four fold with the same resistance.

Applications. The heating of a wire carrying a current is made use of for lighting purposes, and again for blasting, exploding sub-marine mines, etc. Conducting wires are run from the explosive material to a distant point, and include a battery and

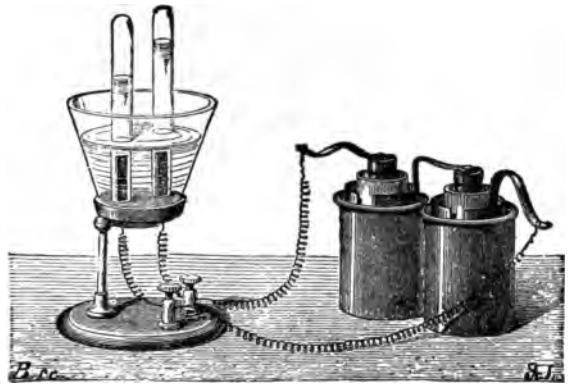


Fig. 32.

piece of fine platinum wire in the circuit. Some combustible substance is placed around the platinum, and serves to ignite the main charge when the platinum wire is heated. Upon closing the circuit this wire becomes hot and the explosion takes place.

This principle of heating is also applied to *fuses*, used for the protection of electric lighting or power circuits. The fuse consists of an easily fusible metal which is inserted in the circuit. The passage of an excessive or dangerously large current heats the fuse to its melting point and so breaks the circuit. The cause of the large current may then be removed and a new fuse inserted in place of the old one.

Electric welding is accomplished by passing a powerful cur-

rent through two rods held together. The heating at the junction softens the metal and the rods become welded.

The electrical heating of cars and of cooking utensils is accomplished by passing a current through wires of high resistance.

Thermo-Electric Currents. If the junction of two dissimilar metals forming part of a circuit, is heated, a current is produced. If a piece of bismuth and a piece of antimony be soldered together and form part of a circuit, then if the junction be heated to a temperature higher than that of the rest of the circuit, a current will flow in the direction from bismuth to antimony through the heated section. If the junction be cooled below the temperature of the rest of the circuit, a current will flow in the opposite direction. The current will continue to flow as long as the difference in temperature is maintained. Currents thus produced are called *thermo-electric* currents. This phenomenon is commonly known as the Seebeck effect from the name of its discoverer.

About the only application of the above phenomenon is made to instruments for detecting very slight differences in temperature. These are arranged so that a very small rise in temperature of a bismuth and antimony junction, will generate a current which may be measured by a sensitive instrument in the circuit. Other metals may be used but the effect is not nearly so pronounced.

CHEMICAL EFFECTS OF CURRENTS.

Electrolysis. When a current of electricity is passed through water from one terminal of a circuit to the other, the water is decomposed into its constituent parts, hydrogen and oxygen. The hydrogen gas rises in bubbles from one terminal and the oxygen gas from the other. Fig. 32 illustrates an arrangement of apparatus by which this decomposition may be attained, and by which the gases may be separately collected. The current from a couple of cells is conducted through one wire to a vessel containing water, then through the liquid and through the other wire to the cells. Pure water is a poor conductor, and a few drops of sulphuric or hydrochloric acid are added to increase its conductivity. The two terminals project through the bottom of the vessel and over each of them is placed a tube closed at the upper

end and filled with water. The gas given off from each terminal rises and collects in the upper portion of the tubes. Oxygen rises from the terminal by which the current enters the liquid and hydrogen from the terminal by which it leaves. Oxygen is therefore collected in one tube and hydrogen in the other. Two volumes of hydrogen and one volume of oxygen unite to form water, and hence in its decomposition the volume of hydrogen collected is twice that of the oxygen.

Other liquids may be decomposed by passing a current through them, and this process of decomposition is called *electrolysis.* Liquids which may be decomposed in this manner are called *electrolytes.* The terminals by which the current enters and leaves the liquid are called *electrodes.* The *anode* is that terminal by which the current enters and the *kathode* is that by which it leaves the liquid.

Some liquids such as oil, which is an insulator, and mercury which is itself an element, cannot be decomposed by an electric current. Dilute acids however, and solutions of metallic salts are readily decomposed.

For an example of the decomposition of a salt we will take a solution of copper sulphate for the electrolyte. The current from a single cell is sufficient to decompose this salt. By passing the current through the liquid, metallic copper is separated from its compound and is deposited in a pure state upon the kathode. The remainder of the compound unites with the water to form sulphuric acid and oxygen. The latter rises in bubbles from the anode. The final result therefore, is that the kathode receives a coating of pure copper and the liquid becomes dilute sulphuric acid. If the anode consists of copper, it will dissolve into the liquid forming copper sulphate as fast as the pure copper is deposited upon the kathode. In this case the action of the current is to transfer the copper from the anode to the kathode.

The amount of chemical action in an electrolytic cell depends upon the strength of current, and the time it continues.

Electrotyping. The decomposition of salts by the electric current has received a most important application in *electrometallurgy.* By this process exact reproductions may be made of type, plaster casts, medals, etc. In the usual process a wax mould

of the object is first made, and this is coated with graphite or powdered bronze to render it a good conductor. The mould is then suspended in, and forms the kathode of an electrolytic cell. For the formation of a copper electrotype, the anode is a plate of copper and the electrolyte is copper sulphate. The passage of the current produces an exact reproduction of the original object on the wax mould. Even the faintest lines are accurately reproduced.

Electroplating. By this process the cheaper metals may receive a thin coating of gold, silver, nickel, etc. The objects to be plated are suspended in the electrolytic cell and form the kathode. In electro-gilding the electrolyte is a solution of double cyanide of gold and potassium, and a plate of gold forms the anode. This plate dissolves into the liquid as fast as the gold coating is deposited upon the objects to be coated. For electro-silvering a double cyanide of silver and potassium and a plate of silver are used. Iron objects are usually coated with a copper deposit before being gilded, silvered or nickeled. The copper presents a better surface for the other metals and gives more durable results.

Accumulators, also called storage or secondary batteries, consist of cells which are capable of giving out electrical energy, in virtue of the chemical change caused by first passing a current through them from an external source.

The simplest type of accumulator is called the Planté battery from the name of its inventor. This cell consists simply of lead plates in dilute sulphuric acid. The plates are "formed" or made active by repeatedly "charging" and "discharging" the cells. That is, a current from an outside source is passed through the cell from one plate to the other, and then by connecting the plates by a wire a current will flow until the potential of each plate is the same. By repeated charging and discharging, the capacity of the cell is greatly increased. No electricity is stored up by the plates as with the Leyden jar, but the effect is due entirely to a chemical change on the surface of the plates. By repeated chargings this chemical change penetrates deeper and deeper into the plates and thus increases their capacity. The current received from the cell flows in an opposite direction to that by which the cell is charged.

THE TELEGRAPH.

Having considered the electromagnet and the effect produced in a core of soft iron, by a current of electricity which passes through a coil of insulated wire surrounding it, we are prepared to apply these principles to the electric telegraph.

Various devices have been tried, with more or less success, for transmitting and recording signals from one point to another.

The apparatus used in one of these early attempts caused sparks from Leyden jars to pass through a circuit. Another was operated by means of a galvanometer needle which was deflected to the right or left.

None of these attempts were of any practical value except that they served to lead up to the telegraph of the present day. There are now two successful methods of operating telegraph lines; namely the "Open Circuit" and the "Closed Circuit" systems. The former is used in Europe and its chief advantage is that no energy is consumed from the batteries except when signals are actually being transmitted. The latter system which is used almost entirely in America, has on the other hand, advantages which offset this. On account of its greater importance in this country we will consider more in detail the "Closed Circuit" system.

In its simplest form this system consists of three principal parts connected in series in the circuit:

1. A key for transmitting the signals.
2. An instrument for receiving these signals.
3. A battery which furnishes the current to operate it.

The Morse Sounder. The instrument most commonly used for receiving the signals is the Morse sounder, shown in Fig. 33. It consists essentially of an inverted electromagnet E of the horse-shoe type. This electromagnet differs somewhat from the one shown in Fig. 27, in that it is made up of two cores and a yoke or back strap B in order to furnish a better bearing for the electromagnet upon its base than would be possible with one having a rounding back. Above the poles of this magnet, an armature A of soft iron is attached to a pivoted lever L of non-magnetic material, which is controlled by a spring S. When a current

passes through the coils of this electromagnet, the cores become magnetized and attract the armature downward. Just before it touches the poles of the electromagnet however, the lever to which it is attached, strikes a metallic stop F and a click is heard. When the current ceases to flow, the cores of the electromagnet

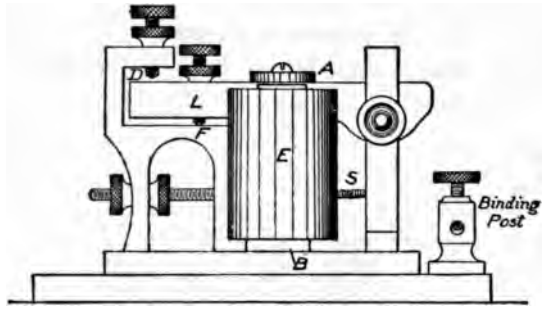


Fig. 33.

lose their attractive force. The armature is then carried upward by means of the spring which acts on the lever to which the armature is attached. The lever then strikes against another stop D and another click is heard. The range of stroke or play of the lever is adjusted by set screws.

AMERICAN MORSE CODE.

A . —	J — . — .	S . . .	2 . . — . .
B — . . .	K — . —	T —	3 . . . — .
C . . .	L ——	U . . —	4 . . . . —
D — . .	M — —	V . . . —	5 — — — —
E .	N — .	W . — —	6 . . . . .
F . — .	O . .	X . — . .	7 — — . .
G — — .	P	Y	8 — . . . .
H	Q . . — .	Z	9 — . . —
I . .	R . . .	1 . — — .	0 ———

If the duration of time of current flow is very short, the interval of time between these two clicks will be correspondingly short. The signal in this case would be a "dot." If the interval between the two clicks be longer, the signal would be a dash.

In this manner by a telegraphic code, consisting of different signals made up of dots, spaces and dashes for all the letters of the alphebet and numbers, it is possible to send and receive messages. Beside the "Sounder" described above in which th.

receiving operator depends entirely upon sound for the message, there are also in use the "Embosser" and the "Ink Writer."

In the first a sharp point attached to the armature lever cuts the dots or dashes in a strip of paper moved past it by clock work; in the second the dots and dashes are recorded on the moving paper by an inked wheel. These last two methods are, however, little used by expert operators.

The Morse Key. The Morse Key or instrument by which the signals are controlled is shown in Fig. 34.

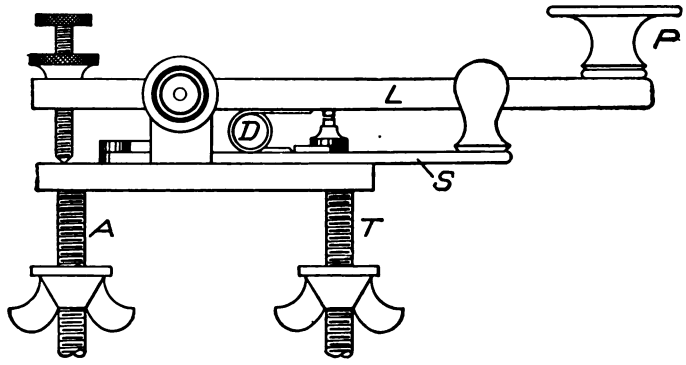


Fig. 34.

It is composed of a pivoted lever L fitted at one end with a circular plate P on which the fingers of the operator rest. The key is secured to the base by two thumb screws A and T, to which the terminals of the circuit are attached. The screw A is in electrical connection with the main body of the key, including the lever. The screw T is insulated from the rest of the key by some non-conducting material, and terminates in a platinum point.

On the under side of the lever and immediately above this point is another platinum tip which, when the lever is pressed down, makes contact, thus completing the circuit through the key.

The lever is kept in proper position when not in use, by a spring D and the length of its stroke is controlled by an adjustable set screw. A switch S, for closing the circuit when the instrument is not in use, completes this piece of apparatus.

The Battery. The battery used for operating the circuit is either the Daniell cell shown in Fig. 20 or the Gravity cell shown in Fig. 23. In the "Closed Circuit" system the batteries are

required to furnish current nearly all the time and these cells are remarkably well adapted for this purpose as they do not polarize and require very little attention other than keeping them supplied with copper sulphate and removing the zinc sulphate.

The number of cells used depends upon the length of the line and resistance of the instruments in the circuit.

In actual practice there is a key and sounder at every station on the line, all being connected in series together with a sufficient number of cells to furnish the current. The switches of all the keys being closed, a current will flow through the electromagnets of all the sounders.

When an operator wishes to communicate with a certain station, he opens the switch of his key, thus breaking the circuit and he can then by means of the lever, call the station and send any message he desires over the line. This message will, of course be simultaneously signalled by all the sounders on the circuit.

When the operator finishes his message he closes the switch and is then prepared to receive the reply.

The Relay. In the case of long lines having many instruments in series, the main current would not be strong enough to properly operate the receiving sounder directly, and the relay is then resorted to.

This instrument consists of a horizontal electromagnet, having a large number of turns in its coils, in series with the main line. It has an armature somewhat like that of the sounder already described. It is however more delicately balanced so that less magnetic force is required to attract it.

When the line current flows through the relay, this armature is drawn against its stop, and thus it makes contact for a local circuit including a Morse sounder and sufficient batteries to work it.

In this manner, the main or line current, although not strong enough to operate the sounder directly, can be made to control the sounder in the local circuit, by means of the relay, the armature of which plays the same part in the local circuit as does the key in the main circuit when manipulated by the operator.

THE TELEPHONE.

The modern telephone was invented in 1876 by Alexander Graham Bell and Elisha Gray. Up to this time, many attempts to perfect a successful speaking apparatus had been made but they were all failures. One cause of lack of success was the fact that the inventors had little or no knowledge of acoustics.

In order to understand the operation of the telephone, it is necessary, first of all, to understand the principles underlying the production of sound, or of acoustics. Sound is produced by vibrations in the air set up by whatever may be the cause producing the sound. These vibrations strike the eardrum, and the sensation of sound is conveyed to the brain. The pitch depends upon the rapidity of the vibration, the loudness upon the amplitude, and the quality upon the form of the vibration.

The simplest sort of vibration is that set up by a musical tone, and to give an idea of the rapidity of vibrations for a specific case it may be stated that the musical tone known as middle C is set up by 256 vibrations per second. The vibrations set up by the

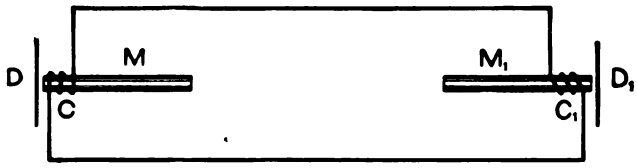


Fig. 35.

voice in speaking are of a much more complex nature in every way, and on this account the earliest telephones could reproduce musical tones, but could not transmit speech.

The earlier telephones served to transmit and reproduce the vibrations of the voice by means of electromagnetic induction. A typical telephone circuit in its simplest form is shown in Fig. 35. There are two similar instruments, one at each end of the circuit; we may consider one the transmitter and the other the receiver. M and M_1 are two permanent bar magnets on the ends of which are coils of fine insulated wire C and C_1. In front of the magnets are thin elastic disks of sheet iron, D and D_1, commonly known as the diaphragms. Let us consider the left-hand instru-

ment the transmitter, and the other the receiver. The permanent magnet M sets up a certain number of magnetic lines of force through the coil C, and as the diaphragm D offers a path of lower magnetic resistance than the air, many of these lines pass through it. When we speak close to the diaphragm D, the air vibrations cause the diaphragm to vibrate. As it approaches the magnet M more magnetic lines pass through the diaphragm, and when it recedes fewer lines pass through it. This action alters the number of magnetic lines which pass through the coil C, and hence alternating currents are induced in it which are proportional in strength to the rate of change of the number of lines.

These currents also pass through the coil C_1 at the receiving end of the line, and according to the direction in which they flow around the magnet M_1, alternately add to or tend to neutralize its strength. When the current strengthens the magnet, it causes it to attract its diaphragm D_1, and when the current decreases the strength of the magnet, the diaphragm moves away. In this manner the diaphragm at the receiving end is made to vibrate in exact

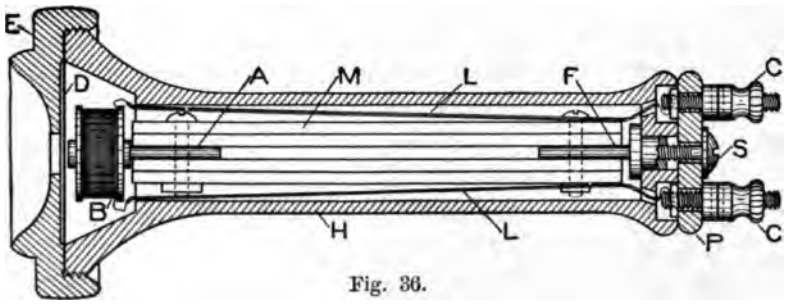


Fig. 36.

unison with the one at the transmitting end, and thus similar vibrations of the air are set up, reproducing the sounds spoken into the transmitter.

The above arrangement has been somewhat modified in the telephone of the present day, and it has been found more convenient to have a separate transmitter at each end of the circuit. The transmitters now in use operate on entirely different principles, but the receiver is essentially the same.

Receivers. There are two common forms of receiver: the single-pole and the bipolar type.

A single-pole receiver of the Bell type is shown in section in Fig. 36. It consists of a hard rubber case H, in which is placed the laminated or compound bar magnet of steel M. This magnet is composed of two sets of bars separately magnetized; clamped between them by means of screws is the pole piece of soft iron A at one end and the block F at the other end. Upon the pole piece is placed a coil of fine insulated copper wire B; connection being made from it to the binding posts C C by means of heavy wires L L. The binding posts are attached to the end piece P, which is held in place by the screw S which threads into the block F, and thus serves also to keep the magnet in position. The cap E screws to the case and supports the diaphragm D, which is a flexible disk of soft iron. The diaphragm is placed a short distance in front of the pole piece of the magnet, and the portion directly opposite it is free to vibrate.

This instrument is being supplanted to a great extent by the bipolar receiver, which differs from the single-pole receiver in that the permanent magnet, instead of being straight, is constructed upon the horse-shoe principle. This brings both poles in position to act on the diaphragm, giving increased strength of field, and consequently making the instrument more efficient. A soft-iron pole piece is secured to each end of the magnet, and a coil of insulated copper wire is mounted on each pole piece.

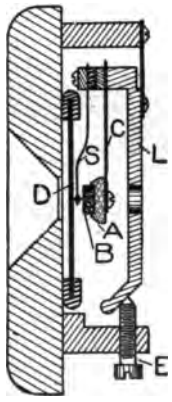


Fig. 37.

At the present time the single-pole receiver is sometimes used for local work, while the bipolar receiver is employed both for this and for long-distance work. There is also another form of receiver known as the watch-case type, which is used to some extent for desk sets and at the exchange switch-board.

Transmitters. The type of telephone just described was originally used as the transmitter as well as the receiver, and for short distances, in which the line resistance was small, gave fairly good results.

It is now the practice to use this instrument as the receiver

only, and to use a different form of instrument, together with a battery, for the transmitter. The action of this transmitter depends upon the fact, that if the resistance of a circuit is increased, the current will be decreased, and if the resistance is decreased, the current will be increased. This variation in resistance is produced by varying the pressure between one or more carbon contacts. If the pressure is increased, the resistance is decreased, and if the pressure is decreased, the resistance is increased.

There are three types of transmitter: in the first but one carbon contact is used for varying the resistance, in the second several contacts are used, and in the third granular carbon is employed, thus giving a very large number of contacts.

The Blake transmitter, a section of which is shown in Fig. 37, is an example of the first type. This instrument, in common with all other transmitters, has a diaphragm D somewhat similar to that of the receiver. This is supported in a rubber ring, and is held in place by two damping springs not shown in the cut. Mounted upon a light spring S, and resting against the back of the center of this diaphragm, is the front electrode, which is a platinum pin. Directly back of this piece of platinum, a carbon button B, which forms the other electrode, is supported by means of a spring C, so adjusted that the carbon button bears lightly against the platinum pin. The tendency of the spring S is to press the platinum pin away from the diaphragm; but this is overcome by the stiffer spring C which bears in the opposite direction, and so keeps the platinum in contact with the diaphragm. The electrode B is mounted in a comparatively heavy socket of brass A. Both electrodes can move freely with the vibrations of the diaphragm; but the carbon, on account of the inertia due to the weight of the brass socket, moves more slowly than the other. Any vibration of the diaphragm will, therefore, result in a variation of the pressure between the two electrodes, and thus vary the resistance of the contact.

The two springs S and C are insulated from each other, and the current goes to the contact point by means of one spring and leaves by the other. The adjustment of the pressure is effected by means of the screw E, which bears against the lever L.

This transmitter is quite satisfactory for lines of moderate

length, and is used to some extent at the present time. It is, however, somewhat difficult to keep in adjustment, and is not well adapted for long-distance work.

The second type of transmitter mentioned is not much used in this country, and a description need not be given.

The most common form of transmitter, and the one which is rapidly replacing all others, is the Hunnings or granular carbon type. This, as originally planned by its inventor, consists of two insulated plates of conducting material which forms the electrodes of the transmitter, the space between them being filled with granular carbon. The general form of this instrument is shown in Fig. 38. D is the diaphragm of metal or carbon which is clamped between the body of the case C and the cap A by means of screws. Another conducting plate B, of metal or carbon, is placed in the back of the case, and the space between D and B is filled with granular carbon. The conducting plates D and B form the electrodes or terminals of this transmitter. When the diaphragm is spoken against, it of course vibrates, and thus varies the pressure upon the numerous contact points of the granular carbon through which the current must flow to pass from one electrode to the other, and thus the resistance is varied as in the Blake instrument. Larger currents can be used with the Hunnings type of transmitter than with other sorts, and it has the further advantage of allowing a greater variation of resistance.

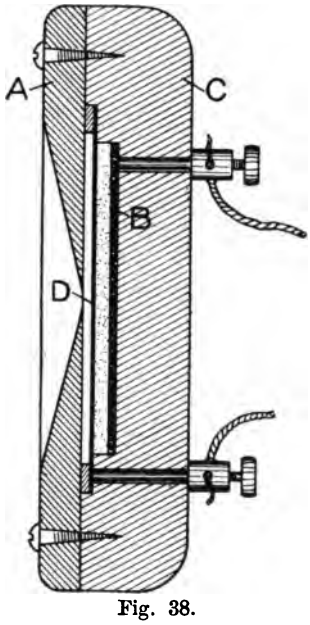


Fig. 38.

The transmitter which is used almost entirely at the present time is known as the "solid back," being a modification of the Hunnings type just described. The case, which is of metal and hollowed out to contain the working parts of the instrument, is enclosed by a brass cover, which also carries the mouth piece. The metal diaphragm is supported in a ring of soft rubber

attached to the back of the cover. The electrodes are enclosed in a metal chamber which is lined with insulating material. This electrode chamber is secured by means of a set screw to a metal bridge which is attached to the back of the cover by means of screws. Both electrodes are of carbon, being in the form of discs somewhat smaller in diameter than the containing chamber. The space between the electrodes is filled with granular carbon as is also the space between the circumference of the discs and the insulated walls of the chamber. The rear electrode is mounted upon a brass disc which is screwed to the back of the chamber, thereby holding the electrode securely in place. This electrode being in metallic connection with the containing chamber, is in electrical connection, through the bridge and cover, with the frame of the transmitter which thus becomes one of the terminals.

The front electrode is also backed by a brass disc which is attached to the metal diaphragm of the transmitter by means of a stud which passes first through a mica washer that serves to enclose the electrode chamber, and then through the center of the diaphragm. This stud is fitted with two threads, upon one of which is screwed a nut which clamps the mica washer to the electrode, and upon the other two nuts which clamp the electrode to the diaphragm. A brass collar, which screws to the periphery of the electrode chamber, binds the mica washer securely against it. Connection is made to the front electrode, which is the second terminal, by means of a fine wire brought out to a binding post mounted upon an insulated block.

The vibrations of the diaphragm are communicated directly to the front electrode, which thus varies the pressure upon the mass of granular carbon and consequently serves to vary the resistance. Two damping springs rest against the diaphragm, thus keeping the amplitude of its vibrations within reasonable limits, and checking them as soon as they have performed their part, leaving the diaphragm ready to obey the impulses due to the succeeding sound waves.

This transmitter operates in a very satisfactory manner; excellent contact is made between the carbon electrodes and the particles of granular carbon. Packing of the granules is pre-

vented on account of the space between the periphery of the electrodes and the inner circumference of the chamber, which contains granules that do not become heated by the passage of the current. Hence when the granules between the electrodes become heated they can expand into this portion.

The transmitters of this type manufactured by different companies vary slightly in minor details of construction, but all operate upon practically the same principles.

Simple Telephone Circuit. The earliest form of telephone circuit consisted simply of two Bell receivers connected in series. The one which was being used as a transmitter served as a very small generator which sent alternating currents over the line, and these acted upon the instrument at the other end of the circuit, which was, for the time being, used as a receiver.

After the invention of the carbon transmitter the circuit consisted of a transmitter and receiver at each end of the line, together with the batteries which furnished the power, all connected in series. This arrangement did not give satisfactory results for many reasons, but the use of the induction coil overcame the difficulties previously met with.

A typical circuit with the induction coil is shown in Fig. 39. Here T is the transmitter, B the battery, P the primary and S the secondary of the induction coil, and R the receiver. The primary

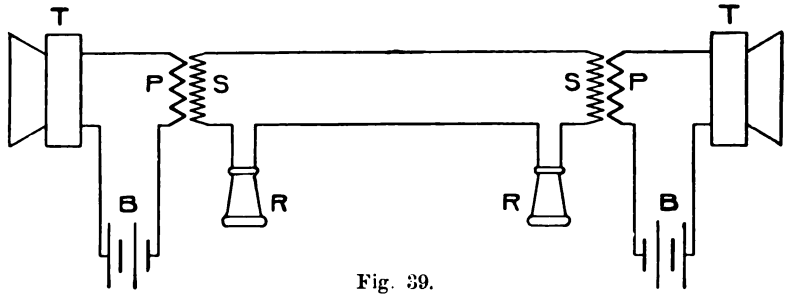


Fig. 39.

circuit contains the transmitter, batteries, and primary of the induction coil, while the secondary circuit contains the receiver and secondary coil. When the transmitter at one end of the line is spoken into, the resistance of the primary circuit is varied, and this in turn varies the strength of the current passing through the

primary of the induction coil. Consequently alternating currents are induced in the secondary coil which pass over the line and act upon the receiver at the opposite end.

The action of the induction coil has already been described. The coil used in telephone work has a core made of soft iron wires. Upon this is wound the primary coil, consisting of a comparatively small number of turns of coarse insulated copper wire, and outside of this, and carefully insulated from it, is the secondary coil in which are a great many turns of fine insulated copper wire. Without the induction coil, it is probable that the long distance telephone in its present state of perfection would have been impossible. Its use allows the resistance of the circuit in which the transmitter acts to be very small; with the result that the effects of the variations in resistance due to the transmitter are comparatively large. This low resistance also permits a larger current to flow with a given number of cells of battery. The electromotive force of the secondary current is high, thus being well adapted to overcome the high resistance of the receivers, secondary coils, and line wires. Still another advantage lies in the fact that if the transmitter were connected directly in the main circuit, its effect would be to cause the current in the line to vary in strength but not to change in direction. In other words, the current would be undulating but not alternating. However, better results are obtained if the current which actuates the receiver be an alternating one, and this is of course the nature of the current in the secondary of the induction coil.

Batteries. In telephone work the batteries are required to furnish current for only short periods of time, and the Leclanche cell is admirably adapted for the purpose. It requires very little attention and will furnish a comparatively large current for a short time. Moreover, although these batteries polarize in a short time if kept on a closed circuit, they recover very quickly when the circuit is opened.

The Fuller cell is also used to a considerable extent. In this cell the plates are zinc and carbon; dilute sulphuric acid is the excitant, and either bichromate of sodium or bichromate of potassium may be used as the depolarizer. The zinc is placed in a porous cup, in the bottom of which is a small quantity of mercury

which serves to amalgamate the surface of the zinc and thus prevent local action between the zinc and the impurities which it contains. This cup is then filled with a solution of sodium chloride (or common salt) dissolved in water. In the battery jar is the solution of dilute sulphuric acid and bichromate of sodium or potassium. The porous cup is put into the jar, and the carbon suspended through an opening in the cover which fits over the jar. This cell is excellent for telephone work; it has a high voltage, low internal resistance, and does not deteriorate on open circuit.

The gravity battery, already described, and the storage battery are used in telephone work when constant service is required. Dry cells are also used extensively, particularly in intercommunicating sets, on account of their cleanliness and convenience.

The Magneto-Generator. The above-described equipment serves to transmit and receive messages, but it is also necessary to supply some sort of calling device. The simplest apparatus for this purpose consists of an ordinary bell or buzzer operated from batteries, and this system is used commonly to-day for office sets where the distance between stations is small.

For long distances it is, however, impracticable to use this system for calling, and recourse is had to the magneto, which is described in another section. This consists of a generator having permanent field magnets and a shuttle armature which is wound with many turns of fine insulated copper wire. The armature is rotated at high speed by means of a small pinion on its shaft which meshes with a larger gear which is turned by means of a crank. This machine furnishes an alternating current, and hence it is necessary to use a polarized bell or ringer in connection with it, so constructed as to operate with an alternating current. Magneto-generators are designated by the resistance through which they will ring, being spoken of as a 10,000-ohm, 20,000-ohm generator, etc.

At the exchange it is quite common to use a power-driven magneto-generator, which may be driven from a small direct or alternating current motor. Also in some cases the motor-generator is used to supply current for ringing purposes.

Circuits of the Telephone. A complete telephone set is made up of three distinct circuits: one for the calling apparatus, one for the transmitting apparatus, and one for the receiving apparatus. The calling apparatus includes the generator and ringer, the transmitting apparatus consists of the transmitter, batteries, and primary, and the receiving apparatus consists of the receiver and secondary of the induction coil.

When the telephone is not in use the calling apparatus must be connected with the line while the transmitting and receiving circuits are both open. On the other hand, when the telephone is used for talking, the calling circuit should be opened, the transmitting circuit should be closed, and the receiving circuit should be connected to the line. These results are accomplished automatically by means of the switch-hook upon which the receiver is hung. This hook is depressed when the receiver is in place, and raised by a spring when it is removed. In this manner the desired connections are made at the proper time.

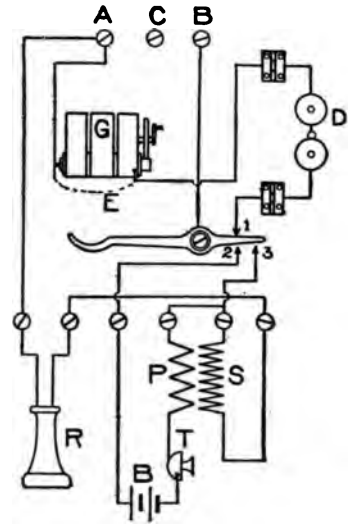


Fig. 40.

There are two types of telephone, differing somewhat in the details of their construction and connections, known as the series telephone and the bridged telephone.

The circuits of a series telephone are shown in Fig. 40. A and B are the line terminals, and C the ground connection for the lightning arrester. When the receiver is on the hook the switch is in the position shown. The generator G and ringer D are in series across the line, through contact point 1, the generator being automatically cut out by the shunt E, when not in use. When the receiver is removed, the contact at 1 is broken, and contact is made at points 2 and 3. The primary circuit is then closed on itself, while the secondary circuit, containing the receiver and secondary of the induction coil, is cut in on the line.

Below there are three pairs of binding posts, to one pair of which the receiver R is connected, to another are connected the terminals of the primary circuit containing the transmitter T, the battery B, and primary P of the induction coil, while the secondary S of the induction coil is connected to the third pair.

Connection is made to the bell through the hinges of the box upon the door of which it is mounted. It is customary to use a ringer of 80 to 120 ohms resistance with series telephones. On account of this low resistance many series telephones cannot be bridged because it would be impossible to ring a number of them in multiple. Moreover, many series telephones could not be connected in series, because, since all the ringers would be constantly in the circuit, it would be impossible to talk through them. Hence this type of telephone is used almost exclusively for city exchange work, not more than two telephones being connected on a line.

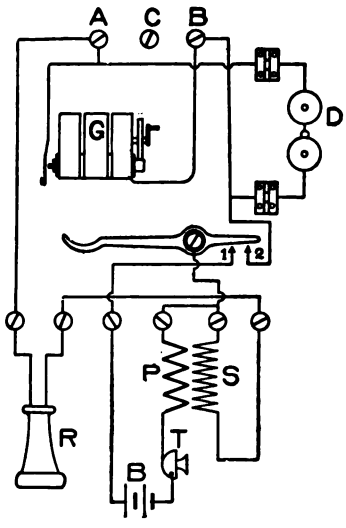
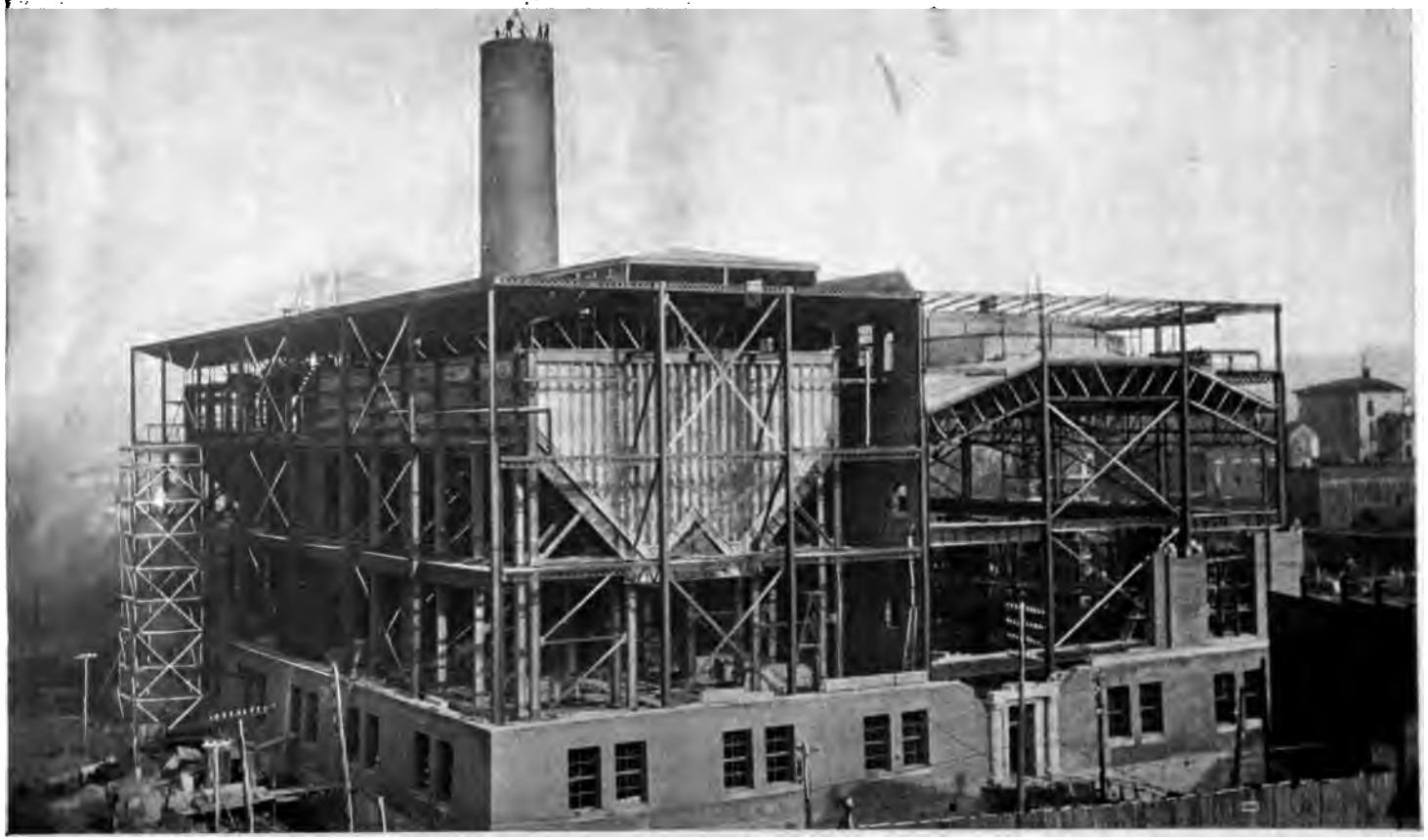


Fig. 41.

The circuits of the bridged telephone are shown in Fig. 41. The ringer coils are permanently bridged across the line. The generator is also bridged, the circuit through it being open when it is not in use, but being closed, usually automatically, when the generator is in operation. When the receiver is taken from the hook, contact is made at points 1 and 2 for the primary and secondary circuits as in the series telephone.

The permanently bridged ringer does not interfere with the action of the receiving circuit, since its coils have a resistance of about 1600 ohms, and are wound so that their self-induction is large. Thus they offer a high impedance to the currents in the receiving circuit because of the extreme rapidity with which they alternate. For this reason a number of these telephones can be bridged upon one circuit, thus forming a party line.

There are three general methods of constructing lines, namely, the grounded circuit, the metallic circuit, and the common return. In the common return the circuit is completed through a copper wire instead of through the ground as in the grounded system, thus eliminating the noise induced by earth currents.



MODERN ELECTRIC POWER STATION IN PROCESS OF ERECTION.
Metropolitan Street Railway Company, Kansas City, Mo.

THE ELECTRIC CURRENT.

Electromotive Force. When a difference of electrical potential exists between two points, there is said to exist an *electromotive force*, or tendency to cause a current to flow from one point to the other. In the voltaic cell one plate is at a different potential from the other, which gives rise to an electromotive force between them. Also in the induction coil, an electromotive force is created in the secondary circuit caused by the action of the primary. This electromotive force is analogous to the *pressure*, caused by a difference in level of two bodies of water connected by a pipe. The pressure tends to force the water through the pipe, and the electromotive force tends to cause an electric current to flow.

The terms potential difference and electromotive force are commonly used with the same meaning, but strictly speaking the potential difference gives rise to the electromotive force. Electromotive force is commonly designated by the letters *E. M. F.* or simply *E.* It is also referred to as *pressure* or *voltage.*

Current. A current of electricity flows when two points, at a difference of potential, are connected by a wire, or when the circuit is otherwise completed. Similarly water flows from a high level to a lower one, when a path is provided. In either case the flow can take place only when the path exists. Hence to produce a current it is necessary to have an electromotive force and a closed circuit. The current continues to flow only as long as the electromotive force and closed circuit exist.

The strength of a current in a conductor is defined as the quantity of electricity which passes any point in the circuit in a unit of time.

Current is sometimes designated by the letter *C*, but the letter *I* will be used for current throughout this and following sections. The latter symbol was recommended by the International Electrical Congress held at Chicago in 1893, and has since been universally adopted.

Resistance. Resistance is that property of matter in virtue of which bodies oppose or resist the free flow of electricity. Water passes with difficulty through a small pipe of great length or through a pipe filled with stones or sand, but very readily through a large clear pipe of short length. Likewise a small wire of considerable length and made of poor conducting material offers great resistance to the passage of electricity, but a good conductor of short length and large cross section offers very little resistance.

Resistance is designated by the letter *R*.

Volt, Ampere and Ohm. The *volt* is the practical unit of electromotive force.

The *ampere* is the practical unit of current.

The *ohm* is the practical unit of resistance. The *microhm* is one millionth of an ohm and the *megohm* is one million ohms.

The standard values of the above units were very accurately determined by the International Electrical Congress in 1893, and are as follows:

The International ohm, or true ohm, as nearly as known, is the resistance of a uniform column of mercury 106.3 centimeters long and 14.4521 grams in mass, at the temperature of melting ice.

The ampere is the strength of current which, when passed through a solution of silver nitrate, under suitable conditions, deposits silver at the rate of .001118 gram per second. Current strength may be very accurately determined by electrolysis, and it is used therefore in determining the standard unit.

The volt is equal to the E. M. F. which, when applied to a conductor having a resistance of one ohm, will produce in it a current of one ampere. One volt equals $\frac{1000}{1434}$ of the E. M. F. of a Clark standard cell at 15° Centigrade.

RESISTANCE.

All substances resist the passage of electricity, but the resistance offered by some is very much greater than that offered by others. Metals have by far the least resistance and of these, silver possesses the least of any. In other words, silver is the best conductor. If the temperature remains the same, the resistance of a

conductor is not affected by the current passing through it. A current of ten, twenty or any number of amperes may pass through a circuit, but its resistance will be unchanged with constant temperature. Resistance is affected by the temperature and also by the degree of hardness. Annealing decreases the resistance of a metal.

Conductance is the inverse of resistance; that is, if a conductor has a resistance of R ohms, its conductance is equal to $\frac{1}{R}$.

Resistance Proportional to Length. The resistance of a conductor is directly proportional to its length. Hence, if the length of a conductor is doubled, the resistance is doubled, or if the length is divided, say into three equal parts, then the resistance of each part is one third the total resistance.

Example. — The resistance of 1283 feet of a certain wire is 6.9 ohms. What is the resistance of 142 feet of the same wire?

Solution. — As the resistance is directly proportional to the length we have the proportion,

$$\text{required resistance} : 6.9 : : 142 : 1283$$

or,
$$\frac{\text{required resistance}}{6.9} = \frac{142}{1283}$$

Hence,
$$\text{required resistance} = 6.9 \times \frac{142}{1283}$$
$$= .76 \text{ ohm (approx.)}$$

Ans. .76 ohm.

Example. — The resistance of a wire having a length of 521 feet is .11 ohm. What length of the same wire will have a resistance of .18 ohm?

Solution. — As the resistance is proportional to length, we have the proportion,

$$\text{required length} : 521 : : .18 : .11$$

or,
$$\frac{\text{required length}}{521} = \frac{.18}{.11}$$

Hence,
$$\text{required length} = 521 \times \frac{.18}{.11}$$
$$= 852 \text{ feet (approx.)}$$

Ans. 852 feet.

Resistance Inversely Proportional to Cross-Section. The resistance of a conductor is inversely proportional to its cross-sectional area. Hence the greater the cross-section of a wire the less is its resistance. Therefore, if two wires have the same length, but one has a cross-section three times that of the other, the resistance of the former is one-third that of the latter.

Example. — The ratio of the cross-sectional area of one wire to that of another of the same length and material is $\frac{257}{101}$. The resistance of the former is 16.3 ohms. What is the resistance of the latter?

Solution. — As the resistances are inversely proportional to the cross-sections, the smaller wire has the greater resistance, and we have the proportion:

$$\text{required resist.} : 16.3 : : 257 : 101$$

or,
$$\frac{\text{required resist.}}{16.3} = \frac{257}{101}$$

Hence,
$$\text{required resist.} = 16.3 \times \frac{257}{101}$$
$$= 41.5 \text{ ohms (approx.)}$$

Ans. 41.5 ohms.

Example. — If the resistance of a wire of a certain length and having a cross-sectional area of .0083 square inch is 1.7 ohms, what would be its resistance if the area of its cross-section were .092 square inch?

Solution. — Since increasing the cross-sectional area of a wire decreases its resistance, we have the proportion,

$$\text{required resist.} : 1.7 : : .0083 : .092$$

or,
$$\frac{\text{required resist.}}{1.7} = \frac{.0083}{.092}$$

Hence,
$$\text{required resist.} = 1.7 \times \frac{.0083}{.092}$$
$$= .15 \text{ ohm (approx.)}$$

Ans. .15 ohm.

As the area of a circle is proportional to the square of its diameter, it follows that the resistances of round conductors are inversely proportional to the squares of their diameters.

Example. — The resistance of a certain wire having a diam.

eter of .1 inch is 12.6 ohms. What would be its resistance if the diameter were increased to .32 inch?

Solution. — The resistances being inversely proportional to the squares of the diameters, we have,

$$\text{required resist.} : 12.6 :: .1^2 : .32^2$$

or,
$$\frac{\text{required resist.}}{12.6} = \frac{.1^2}{.32^2}$$

Hence,
$$\text{required resist.} = 12.6 \times \frac{.1^2}{.32^2}$$
$$= \frac{12.6 \times .01}{.1024}$$
$$= 1.23 \text{ ohms (approx.)}$$

Ans. 1.23 ohms.

Specific Resistance. The specific resistance of a substance is the resistance of a portion of that substance of unit length and unit cross-section at a standard temperature. The unit commonly used is the centimeter or inch, and the temperature that of melting ice. The specific resistance may therefore be said to be the resistance (usually stated in microhms) of a centimeter cube or inch cube at the temperature of melting ice. If the specific resistances of two substances are known then their relative resistance is given by the ratio of the specific resistances.

Conductivity is the reciprocal of specific resistance.

Example. — A certain copper wire at the temperature of melting ice has a resistance of 29.7 ohms. Its specific resistance (resistance of 1 centimeter cube in microhms) is 1.594, and that of platinum is 9.032. What would be the resistance of a platinum wire of the same size and length of the copper wire, and at the same temperature?

Solution. — The resistance would be in direct ratio of the specific resistances, and we have the proportion:

$$\text{required resist.} : 29.7 :: 9.032 : 1.594$$

Hence,
$$\text{required resist.} = 29.7 \times \frac{9.032}{1.594}$$
$$= 168. \text{ ohms (approx.)}$$

Ans. 168. ohms.

Calculation of Resistance. From the preceding pages it is evident that resistance varies directly as the length, inversely as

the cross-sectional area, and depends upon the specific resistance of the material. This may be expressed conveniently by the formula,

$$R = s\frac{L}{A}$$

in which R is the resistance, L the length of the conductor, A the area of its cross section, and s the specific resistance of the material.

Example.— A telegraph relay is wound with 1,800 feet of wire .010 inch in diameter, and has a resistance of 150 ohms. What will be its resistance if wound with 400 feet of wire .022 inch in diameter?

Solution.— If the wires were of equal length, we should have the proportion,

$$\text{Required resistance} : 150 : : (.010)^2 : (.022)^2$$

or, $$\text{Required resistance} = 150 \times \frac{(.010)^2}{(.022)^2} = 30.99+ \text{ ohms.}$$

For a wire 400 feet long, we have, therefore, by direct proportion,

$$\text{Required resistance} = \frac{400}{1{,}800} \times 30.99 = 6.88+.$$

Ans. 6.88+ ohms.

If a circuit is made up of several different materials joined in series with each other, the resistance of the circuit is equal to the sum of the resistances of its several parts. In calculating the resistance of such a circuit, the resistance of each part should first be calculated, and the sum of these resistances will be the total resistance of the circuit.

The table on page 9 gives the resistance of chemically pure substances at 0° Centigrade or 32° Fahrenheit in International ohms. The first column of numbers gives the relative resistances when that of annealed silver is taken as unity. For example, mercury has 62.73 times the resistance of annealed silver. The second and third columns give the resistances of a foot of wire .001 inch in diameter, and of a meter of wire 1 millimeter in diameter, respectively. The fourth and fifth columns give respectively the resistance in microhms of a cubic inch and cubic centimeter, that is, the specific resistances.

Table Showing Relative Resistance of Chemically Pure Substances at Thirty-two Degrees Fahrenheit in International Ohms.

Metal.	Relative Resistance.	Resistance of a wire 1 foot long, .001 inch in diameter.	Resistance of a wire 1 meter long, 1 millimeter in diameter.	Resistance in Microhms.	
				Cubic Inch.	Cubic Centimeter.
Silver, annealed.	1.000	9.023	.01911	.5904	1.500
Copper, annealed.	1.063	9.585	.02028	.6274	1.594
Silver, hard drawn.	1.086	9.802	.02074	.6415	1.629
Copper, hard drawn.	1.086	9.803	.02075	.6415	1.629
Gold, annealed.	1.369	12.35	.02613	.8079	2.052
Gold, hard drawn.	1.393	12.56	.02661	.8224	2.088
Aluminum, annealed	1.935	17.48	.03700	1.144	2.904
Zinc, pressed.	3.741	33.76	.07143	2.209	5.610
Platinum, annealed.	6.022	54.34	.1150	3.555	9.032
Iron, annealed.	6.460	58.29	.1234	3.814	9.689
Lead, pressed.	13.05	117.7	.2491	7.706	19.58
German silver.	13.92	125.5	.2659	8.217	20.87
Platinum-silver alloy ($\frac{1}{3}$ platinum, $\frac{2}{3}$ silver.)	16.21	146.3	.3097	9.576	24.32
Mercury.	62.73	570.7	1.208	37.05	94.06

It should be noted that the resistances in the above table are for chemically pure substances, and also at 32° Fahrenheit. A very small portion of foreign matter mixed with a metal greatly increases its resistance. An alloy of two or more metals always has a higher specific resistance than that of any of its constituents. For example, the conductivity of silver mixed with 1.2 per cent in volume of gold, will be 59 when that of pure silver is taken as 100. Annealing reduces the resistance of metals.

The following examples are given to illustrate the use of the table above in connection with the formula at the top of page 8, and to show the application of preceding laws.

Example. — From the specific resistance of annealed aluminum as given in the next to the last column of the table, calculate the resistance given in the second column of figures for that substance.

Solution. — The resistance in microhms of a cubic inch of annealed aluminum at 32° F. is 1.144, which is equal to .000001144 ohms. The resistance of a wire 1 foot long and .001

inch in diameter is required. In the formula on page 8, we have $s = .000001144$, $L = 1$ foot $= 12$ inches and

$$A = \frac{\pi d^2}{4} = \frac{3.1416 \times .001^2}{4} = .0000007854 \text{ sq. in.}$$

Substituting these values in the formula,

$$R = s\frac{L}{A}$$

we have,

$$R = .000001144 \times \frac{12}{.0000007854}$$

$$= 17.48 \text{ ohms.} \qquad \text{Ans. 17.48 ohms.}$$

Example.—The resistance in microhms of a cubic centimeter of annealed platinum at 32° F. is 9.032. What is the resistance of a wire of the same substance one meter long and one millimeter in diameter at the same temperature?

Solution. —In the formula for resistance we have the quantities $s = 9.032$ microhms $= .000009032$ ohms; $L = 1$ meter $=$ 100 centimeters; and

$$A = \frac{\pi d^2}{4} = \frac{3.1416 \times .1^2}{4} = .007854 \text{ sq. cm.}$$

the diameter being equal to 1 millimeter $= .1$ cm.

Substituting these values we have,

$$R = .000009032 \times \frac{100}{.007854}$$

$$= .1150 \text{ ohms.} \qquad \text{Ans. .115 ohms.}$$

Example. —From the table the resistance of 1 ft. of pure annealed silver wire .001 inch in diameter at 32° F. is 9.023 ohms. What is the resistance of a mile of wire of the same substance .1 inch in diameter at that temperature?

Solution. — As the resistance of wires is directly proportional to their length and inversely proportional to the squares of their diameters, the required resistance is found by multiplying the resistance per foot by 5,280 and the product by the inverse squares of the diameters.

$$\text{Therefore } R = 9.023 \times 5280 \times \left\{\frac{.001}{.1}\right\}^2$$

$$= 4.76 \text{ ohms (approx.)}$$

Ans. 4.76 ohms,

Example.—A mile and one-half of an annealed wire of pure iron has a resistance of 46.1 ohms. What would be the resistance of hard drawn wire of pure copper of the same length and diameter, assuming each to be at the temperature of melting ice?

Solution. — The only factor involved by this example is the relative resistance of the two metals. From the table, page 9, annealed iron has 6.460 and hard-drawn copper 1.086 times the resistance of annealed silver. Hence the resistance of the copper is to that of the iron as 1.086 is to 6.460, and the required resistance is

$$R = 46.1 \times \frac{1.086}{6.460} = 7.75 \text{ ohms (approx.)}$$

Ans. 7.75 ohms.

Example. — If the resistance of a wire 7,423 feet long is 18.7 ohms, what would be its resistance if its length were reduced to 6,253 feet and its cross-section made one half again as large?

Solution. — As resistance is directly proportional to the length, and inversely proportional to the area of the cross-section, the required resistance is

$$R = 18.7 \times \frac{6253}{7423} \times \frac{2}{3} = 10.5 \text{ ohms (approx.)}$$

Ans. 10.5 ohms.

Resistance Affected by Heating. The resistance of metals depends upon the temperature, and the resistance is increased by heating. The heating of some substances, among which is carbon, causes a decrease in their resistance. The resistance of the filament of an incandescent lamp when lighted is only about half as great as when cold. All *metals*, however, have their resistance increased by a rise in temperature. The percentage increase in resistance with rise of temperature varies with the different metals, and varies slightly for the same metal at different temperatures. The increase is practically uniform for most metals throughout a considerable range of temperature. The resistance of copper increases about .4 per cent. per degree Centigrade, or about .22 per cent. per degree Fahrenheit. The percentage increase in resistance for alloys is much less than for the simple metals. Standard resistance coils are therefore made of alloys, as it is desirable that their resistance should be as nearly constant as possible.

The change in resistance of one ohm per degree rise in temperature for a substance is called the *temperature coefficient* for that substance. The following table gives the temperature coefficients for a few substances.

TEMPERATURE COEFFICIENTS.

MATERIAL.	RISE IN R. OF 1 OHM WHEN HEATED: 1° F.	1° C.
Platinoid	.00012	.00022
Platinum-silver	.00014	.00025
German silver	.00022	.00040
Platinum	.0019	.0035
Silver	.0021	.0038
Copper, aluminum	.0022	.0040
Iron	.0026	.0046

If the resistance of a conductor at a certain temperature is known, the resistance the conductor will have at a higher temperature may be found by multiplying the temperature coefficient for the substance, by the number of degrees increase and by the resistance at the lower temperature, and adding to this result the resistance at the lower temperature. The product of the temperature coefficient by the number of degrees increase gives the increase in resistance of one ohm through that number of degrees, and multiplying this by the number of ohms gives the increase in resistance for the conductor. The result obtained is practically correct for moderate ranges of temperature.

The above method of calculating the resistance of conductors at increased temperatures is conveniently expressed by the following formula:

$$R_2 = R_1 (1 + a\, t)$$

where R_2 is the resistance at the higher temperature, R_1 that at the lower temperature, a the temperature coefficient for the substance and t the number of degrees change.

From the preceeding formula it follows that if the resistance at the higher temperature is known, that at the lower temperature will be given by the formula:

$$R_1 = \frac{R_2}{1 + a t}$$

In calculating resistances at different temperatures, the temperature coefficient based on the Fahrenheit scale should be used if the number of degrees change is given in degrees Fahrenheit, and that based on the Centigrade scale if given in degrees Centigrade.

Example.— The resistance of a coil of German silver wire at 12° C. is 1304 ohms. What would be its resistance at a temperature of 60° C.?

Solution.— From the statement of the example $R_1 = 1304$, $t = 60 - 12 = 48$, and from the table page 12, $a = .0004$. Substituting these values in the first of the preceding formulas we have,

$$\begin{aligned} R_2 &= 1304\ (1 + .0004 \times 48) \\ &= 1304 \times 1.0192 \\ &= 1329 \text{ ohms (approx.)} \end{aligned}$$

Ans. 1329 ohms.

Example. — If the resistance of a copper conductor at 95° F. is 48.2 ohms, what would be the resistance of the same conductor at 40° F.?

Solution. — In this case $R_2 = 48.2$, $t = 95 - 40 = 55$, and from the table $a = .0022$. Substituting these values in the formula at the foot of page 12, we have,

$$R_1 = \frac{48.2}{1 + .0022 \times 55} = \frac{48.2}{1.121}$$
$$= 43. \text{ ohms (approx.)}$$

Ans. 43 ohms.

The first table on page 14 gives the resistance of the most common sizes of copper wire according to the American or Brown and Sharpe (B. & S.) gauge. The resistance given is for pure copper wire at a temperature of 75° F. or 24° C.

The first column gives the number of the wire, the second the diameter in thousandths of an inch or mils, and the third the diameter in millimeters, The fourth column gives the equivalent number of wires each one mil or one thousandth of an inch in diameter. This is called the size of the wire in circular mils and is equal to the square of the diameter in mils. The fifth column gives the ohms per thousand feet and the resistance per mile is found by multiplying these values by 5.28. Ordinary commercial

copper has a conductivity of about 95 to 97 per cent. of that of pure copper. The resistance of commercial wire is therefore about 3 to 5 per cent. greater than the values given in the table. The resistance for any metal other than copper may be found by multiplying the resistance given in the table by the ratio of the specific resistance of the given metal to the specific resistance of copper.

American Wire Gauge (B. & S.)

No.	Diameter in		Circular Mils.	Ohms per 1000 Ft.	No.	Diameter in		Circular Mils.	Ohms per 1000 Ft.
	Mils.	Millim.				Mils.	Millim.		
0000	460.00	11.684	211600.0	.051	19	35.89	.912	1288.0	8.617
000	409.64	10.405	167805.0	.064	20	31.96	.812	1021.5	10.566
00	364.80	9.266	133079.4	.081	21	28.46	.723	810.1	13.328
0	324.95	8.254	105592.5	.102	22	25.35	.644	642.7	16.799
1	289.30	7.348	83694.2	.129	23	22.57	.573	509.5	21.185
2	257.63	6.544	66373.0	.163	24	20.10	.511	404.0	26.713
3	229.42	5.827	52634.0	.205	25	17.90	.455	320.4	33.684
4	204.31	5.189	41742.0	.259	26	15.94	.405	254.0	42.477
5	181.94	4.621	33102.0	.326	27	14.19	.361	201.5	53.563
6	162.02	4.115	26250.5	.411	28	12.64	.321	159.8	67.542
7	144.28	3.665	20816.0	.519	29	11.26	.286	126.7	85.170
8	128.49	3.264	16509.0	.654	30	10.03	.255	100.5	107.391
9	114.43	2.907	13094.0	.824	31	8.93	.227	79.7	135.402
10	101.89	2.588	10381.0	1.040	32	7.95	.202	63.2	170.765
11	90.74	2.305	8234.0	1.311	33	7.08	.180	50.1	215.312
12	80.81	2.053	6529.9	1.653	34	6.30	.160	39.7	271.563
13	71.96	1.828	5178.4	2.084	35	5.61	.143	31.5	342.443
14	64.08	1.628	4106.8	2.628	36	5.00	.127	25.0	431.712
15	57.07	1.450	3256.7	3.314	37	4.45	.113	19.8	544.287
16	50.82	1.291	2582.9	4.179	38	3.96	.101	15.7	686.511
17	45.26	1.150	2048.2	5.269	39	3.53	.090	12.5	865.046
18	40.30	1.024	1624.1	6.645	40	3.14	.080	9.9	1091.865

The following table gives the size of the English or Birmingham wire gauge. The B. & S. is however much more frequently used in this country. The Brown and Sharpe gauge is a little smaller than the Birmingham for corresponding numbers.

Stubs' or Birmingham Wire Gauge (B. W. G.)

No.	Diameter in		No.	Diameter in		No.	Diameter in	
	Mils.	Millim.		Mils.	Millim.		Mils.	Millim.
0000	454	11.53	8	165	4.19	18	49	1.24
00	380	9.65	10	134	3.40	20	35	0.89
1	300	7.62	12	109	2.77	24	22	0.55
4	238	6.04	14	83	2.11	30	12	0.31
6	203	5.16	16	65	1.65	36	4	0.10

EXAMPLES FOR PRACTICE.

1. What is the resistance of an annealed silver wire 90 feet long and .2 inch in diameter at 32° F.? Ans. .02+ ohm.

2. What is the resistance of 300 meters of annealed iron wire 4 millimeters in diameter when at a temperature of 0° C.? Ans. 2.31+ ohms.

3. What is the resistance of 2 miles of No. 27 (B. & S.) pure copper wire at 75° F.? Ans. 565.+ ohms.

4. The resistance of a piece of copper wire at 32°F. is 3 ohms. What is its resistance at 49°F.? Ans. 3.11+ ohms.

5. The resistance of a copper wire at 52°F. is 7 ohms. What is its resistance at 32°F.? Ans. 6.70+ ohms.

6. What is the resistance of 496 ft. of No. 10 (B. & S.) pure copper wire at 45°F.? Ans. .483+ ohms.

On pages 16 and 17 is given a table disclosing among other data the resistance of various primary cells. The resistance of a circuit of which a battery forms a part, is made up of the external resistance, or the resistance of outside wires and connections, and the internal resistance, or the resistance of the battery itself. The table referred to gives in the first column the name of the cell. In the second and third column appears the name of the anode and kathode respectively. These terms are commonly used with reference to electrolysis but may also be applied to primary cells. The current passes from the anode to the kathode through the cell, and therefore with reference to the cell itself, the anode may be considered the positive element and the kathode the negative element. In regard to the outside circuit however, the current passes of course, from the kathode to the anode, and hence with reference to the outside circuit the kathode is positive and the anode negative; ordinarily the external circuit is considered. As the anode of almost all primary cells is zinc it may readily be remembered that the current passes from the other element *to* the zinc through the *external* circuit. The fourth and fifth columns of the table give the excitant and depolarizer respectively. The sixth column gives the E. M. F. of each cell when it is supplying no current, and the last column gives the internal resistance in ohms.

TABLE IN RELATION TO PRIMARY CELLS, ELECTROMOTIVE FORCE, RESISTANCE, ETC.

NAME OF CELL.	ANODE.	KATHODE.	EXCITANT.	DEPOLARIZER.	E. M. F. IN VOLTS.	INTERNAL RESISTANCE IN OHMS.
Volta (Wollaston, etc.)	Zinc	Copper	Solution of Sulphuric Acid (H_2SO_4)	None	1 to 0.5	
Smee	Zinc	Platinized Silver	Solution of Sulphuric Acid (H_2SO_4)	None	1 to 0.5	0.5
Law	Zinc	Carbon	Solution of Sulphuric Acid (H_2SO_4)	None	1 to 0.5	
Poggendorff (Grenet)	Zinc	Graphite (Carbon)	Solution of Sulphuric Acid (H_2SO_4)	Potassium Dichromate ($K_2Cr_2O_7$)	2.1	
Poggendorff (Grenet) two fluid	Zinc	Graphite (Carbon)	Saturated Solution of Potassium Dichromate and Sulphuric Acid	None Separate	1.98	.001 to .08
Grove	Zinc	Platinum	Sulphuric Acid dilute (H_2SO_4)	Nitric Acid (HNO_3)	1.96	0.1 to 0.12
Bunsen	Zinc	Graphite (Carbon)	Sulphuric Acid dilute (H_2SO_4)	Nitric Acid	1.8 to 1.98	0.08 to 0.11
				Chromic Acid	1.8	0.1 to 0.12
Leclanche	Zinc	Graphite (Carbon)	Ammonium Chloride (NH_4Cl)	Manganese Dioxide (MnO_2)	1.4 to 1.6	1.13 to 1.15
Lalande Lalande—Chaperon	Zinc	Graphite (Carbon)	Caustic Potash or Potassium Hydrate (KOH)	Cupric Oxide	0.8 to 0.98	1.3
Upward	Zinc	Graphite (Carbon)	Zinc Chloride ($ZnCl_2$)	Chlorine (Cl)	2.0	
Fitch	Zinc	Graphite (Carbon)	Ammonium Chloride (NH_4Cl)	Sodium & Potassium Chlorates ($NaClO_3 + KClO_3$)	1.1	
Papst	Iron	Graphite (Carbon)	Ferric Chloride (Fe_2Cl_6)	(Fe_2Cl_6)	0.4	
Obach (dry)	Zinc	Graphite (Carbon)	Ammonium Chloride (NH_4Cl) in Calcium Sulphate ($CaSO_4$)	Manganese Dioxide (MnO_2)	1.46	
Daniell (Meidinger Minotto, etc.)	Zinc	Copper	Zinc Sulphate ($ZnSO_4$)	Copper Sulphate ($CuSO_4$)	1.079	2 to 5
De la Rue	Zinc	Silver	Ammonium Chloride	Silver Chloride ($AgCl$)	1.03 to 1.42	0.4 to 0.6
Marie Davy	Zinc	Graphite (Carbon)	Sulphuric Acid dilute (H_2SO_4)	Paste of Sulphate of Mercury (Hg_2SO_4)	1.52	0.75 to 1
Clark (Standard)	Zinc	Mercury	Zinc Sulphate ($ZnSO_4$)	Mercurous Sulphate (Hg_2SO_4)	1.434*	0.3 to 0.5
Weston	Cadmium	Mercury	Cadmium Sulphate ($CdSO_4$)	Mercurous Sulphate (Hg_2SO_4)	1.025	

NAME OF CELL.	ANODE.	KATHODE.	EXCITANT.	DEPOLARIZER.	E. M. F. IN VOLTS.	INTERNAL RESISTANCE IN OHMS.
Von Helmholtz	Zinc	Mercury	Zinc Chloride ($Zn\,Cl_2$)	Mercurous Chloride ($Hg_2\,Cl_2$)	1.0	
Chromic Acid single fluid	Zinc	Graphite (Carbon)	Sulphuric and Chromic Acids, dilute mixed	None Separate	2.2	.016 to .08
Fuller	Zinc	Graphite (Carbon)	Sulphuric Acid ($H_2\,SO_4$)	Potassium Dichromate ($K_2\,Cr_2\,O_7$)	2.0	0.5 to 0.7
Gaiffe	Zinc	Silver	Zinc Chloride ($Zn\,Cl_2$)	Silver Chloride ($Ag\,Cl$)	1.02	0.5 to 0.6
Maiche	Zinc scraps in bath of Mercury	Platinized Carbon	Common Salt Solution *i. e.* Sodium Chloride ($NaCl$)	None Separate	1.25	1 to 2
Niaudet	Zinc	Graphite (Carbon)	Common Salt Solution *i. e.* Sodium Chloride ($NaCl$)	Chloride of Calcium (Lime) ($Ca\,Cl_2$)	1.0 to 1.6	5 to 6
Schanschieff	Zinc	Graphite (Carbon)	Mercurial Solution	None Separate	1.56	0.05 to 0.75
Skrivanoff	Zinc	Silver	Caustic Potash or Potassium Hydrate (KOH)	Chloride of Silver ($Ag\,Cl$)	1.5	1.5

* At 15 degrees Centigrade or 59 degrees Fahrenheit.

Resistances in last column measured in cells standing 6″ × 4″

OHM'S LAW.

One of the most important and most used laws of electricity is that first formulated by Dr. G. S. Ohm, and known as Ohm's law. This law is as follows:

The current is directly proportional to the electromotive force and inversely proportional to the resistance.

That is, if the electromotive force applied to a circuit is increased, the current will be increased in the same proportion, and if the resistance of a circuit is increased then the current will be decreased proportionally. Likewise a decrease in the electromotive force causes a proportional decrease in current and a decrease in resistance causes a proportional increase in current. The current depends only upon the electromotive force and resistance and in the manner expressed by the above simple law. The law may be expressed algebraically as follows:

$$\text{current } \textit{varies as } \frac{\text{electromotive force}}{\text{resistance}}$$

The units of these quantities, the ampere, volt and ohm, have been so chosen that an electromotive force of 1 volt applied to a resistance of 1 ohm, causes 1 ampere of current to flow. Ohm's law may therefore be expressed by the following equation:

$$I = \frac{E}{R}$$

where I is the current in amperes, E the electromotive force in volts and R the resistance in ohms.

It is therefore evident, that if the electromotive force and resistance are known the current may be found, or if any two of the three quantities are known the third may be found. If the current and resistance are known the electromotive force may be found from the formula:

$$E = R\,I$$

and if the current and electromotive force are known, the resistance may be found from the formula:

$$R = \frac{E}{I}$$

Simple Applications. The following examples are given to illustrate the simplest applications of Ohm's law.

Example. — If the E.M.F. applied to a circuit is 4 volts and its resistance is 2 ohms, what current will flow?

Solution. — By the formula for current,

$$I = \frac{E}{R} = \frac{4}{2} = 2 \text{ amperes.}$$

Ans. 2 amperes.

Example. — What voltage is necessary to cause a current of 23 amperes to flow through a resistance of 820 ohms?

Solution. — By the formula for E.M.F.,

$$E = RI = 820 \times 23 = 18{,}860 \text{ volts.}$$

Ans. 18,860 volts.

Example. — The E.M.F. applied to a circuit is 110 volts, and it is desired to obtain a current of .6 ampere. What should be the resistance of the circuit?

Solution. — By the formula for resistance,

$$R = \frac{E}{I} = \frac{110}{.6} = 183.+ \text{ ohms.}$$

Ans. 183. ohms.

Series Circuits. A circuit made up of several parts all joined in series with each other, is called a series circuit and the resistance of the entire circuit is of course the sum of the separate resistances. In calculating the current in such a circuit the total resistance must first be obtained, and the current may then be found by dividing the applied or total E.M.F. by the total resistance. This is expressed by the formula,

$$I = \frac{E}{R_1 + R_2 + R_3 + \text{etc.}}$$

Example. — Three resistance coils are connected in series with each other and have a resistance of 8, 4 and 17 ohms respectively. What current will flow if the E.M.F. of the circuit is 54 volts?

Solution. — By the preceding formula,

$$I = \frac{E}{R_1 + R_2 + R_3} = \frac{54}{8 + 4 + 17} = \frac{54}{29} = 1.8+ \text{ amperes.}$$

Ans. 1.8+ amperes.

Example. — Six arc lamps, each having a resistance of 5 ohms, are connected in series with each other and the resistance of the connecting wires and other apparatus is 3.7 ohms. What must be the pressure of the circuit to give a desired current of 9.6 amperes?

Solution. — The total resistance of the circuit is $R = (6 \times 5) + 3.7 = 33.7$ ohms and the current is to be $I = 9.6$ amperes. Hence by the formula for E.M.F.,

$$E = R\,I = 33.7 \times 9.6 = 323.+ \text{ volts.}$$

Ans. 323.+ volts.

Example. — The current passing in a certain circuit was 12 amperes and the E.M.F. was 743 volts. The circuit was made up of 4 sections all connected in series, and the resistance of three sections was 16, 9 and 26 ohms respectively. What was the resistance of the fourth section?

Solution. — Let x = the resistance of the fourth section, then $R = 16 + 9 + 26 + x = 51 + x$, $I = 12$, and $E = 743$. By the formula for resistance,

$$R = \frac{E}{I} \text{ or, } \quad 51 + x = \frac{743}{12} = 61.9 \text{ ohms (approx.)}$$

If $51 + x = 61.9$ we have, by transposing 51 to the other side of the equation,

$$x = 61.9 - 51 = 10.9 \text{ ohms.}$$

Ans. 10.9 ohms.

Example. — A current of 54 amperes flowed through a circuit when the E.M.F. was 220 volts. What resistance should be added in series with the circuit to reduce the current to 19 amperes?

Solution. — The resistance in the first case was,

$$R = \frac{220}{54} = 4.07 \text{ ohms (approx.)}$$

The resistance in the second must be,

$$R = \frac{220}{19} = 11.58 \text{ ohms (approx.)}$$

The required resistance to insert in the circuit is the difference of these two resistances, or $11.58 - 4.07 = 7.51$ ohms.

Ans. 7.51 ohms.

Fall of Potential in a Circuit. Fig. 1 illustrates a series circuit in which the resistances A, B, C, D and E are connected in series with each other and with the source of electricity. If the E. M. F. is known, the current may be found by dividing the E. M. F. by the sum of all the resistances. Ohm's law may, however, be applied to any part of a circuit separately, as well as to the complete circuit. Suppose the resistances of A, B, C, D and E are 4, 3, 6, 3 and 4 ohms respectively, and assume that the source has no resistance. Suppose the current flowing to be 12 amperes. The E. M. F. necessary to force a current of 12 amperes through the resistance A of 4 ohms is, by applying Ohm's law, equal to $E = RI = 4 \times 12 = 48$ volts. Hence between the points a and b outside of the resistance A, there must be a difference of potential of 48 volts to force the current through this resistance. Also to force the same current through B, the voltage necessary is $3 \times 12 = 36$. Similarly, for each part C, D and E, there are required 72, 36 and 48 volts respectively.

As 48 volts are necessary for part A and 36 volts for part B, it is evident that to force the current through both parts a difference of potential of $48 + 36 = 84$ volts is required; that is, the

voltage between the points *a* and *c* must be 84 volts. For the three parts *A*, *B* and *C*, 48 + 36 + 72 = 156 volts are necessary, and for the entire circuit, 240 volts must be applied to give the current of 12 amperes. From the above it is evident that there is a gradual fall of potential throughout the circuit, and if the voltage between any two points of the circuit be measured, the E. M. F. obtained would depend upon the resistance included between these two points. For example, the voltage between points *b* and *d* would be found to be 72 + 36 = 108 volts, or between *d* and *e* 36, volts, etc. From the preceding it is apparent that the fall of potential in a part of a circuit is equal to the current multiplied by the resistance of that part.

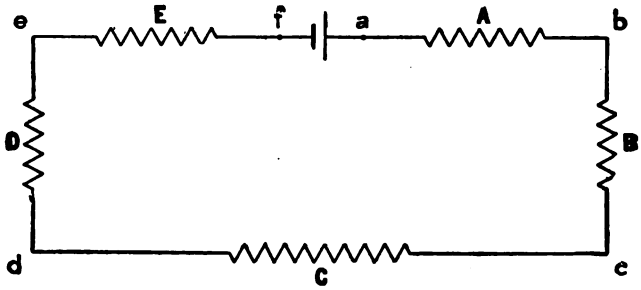


Fig. 1.

This gradual fall of potential, or *drop* as it is commonly called, throughout a circuit, enters into the calculations for the size of conductors or mains supplying current to distant points. The resistances of the conductors cause a certain drop in transmitting the current, depending upon their size and length, and it is therefore necessary that the voltage of machines at the supply station shall be great enough to give the voltage necessary at the receiving stations as well as the additional voltage lost in the conducting mains.

For example, in Fig. 1 the voltage necessary between the points *e* and *b* is 144 volts, but to give this voltage the source must supply in addition the voltage lost in parts *A* and *E*, which equals 96 volts.

Example.—The voltage required by 17 arc lamps connected in series is 782 volts and the current is 6.6 amperes. The resist-

ance of the connecting wires is 7 ohms. What must be the E. M. F. applied to the circuit?

Solution.—The drop in the connecting wires is $E = RI = 7 \times 6.6 = 46.2$ volts. The E. M. F. necessary is therefore 782 + 46.2 = 828.2 volts. Ans. 828.2 volts.

Example.—The source of E. M. F. supplies 114 volts to a circuit made up of incandescent lamps and conducting wires. The lamps require a voltage of 110 at their terminals, and take a current of 12 amperes. What should be the resistance of the conducting wires in order that the lamps will receive the necessary voltage?

Solution.—The allowable drop in the conducting wires is 114 — 110 = 4 volts. The current to pass through the wires is 12 amperes. Hence the resistance must be

$$R = \frac{E}{I} = \frac{4}{12} = .33 + \text{ohms.}$$

Ans. .33 + ohms.

Divided Circuits. When a circuit divides into two or more parts, it is called a *divided* circuit and each part will transmit a portion of the current.

Such a circuit is illustrated in Fig. 2, the two branches being represented by *b* and *c*. The current passes from the positive pole of the battery through *a* and then divides; part of the current passing through *b* and part through *c*. The current then unites and passes through *d* to the negative pole of the battery. The part *c* may be considered as the main part of the circuit and *b* as a by-pass about it. A branch which serves as a by-pass to another circuit is called a *shunt* circuit, and the two branches are said to be connected in *parallel*.

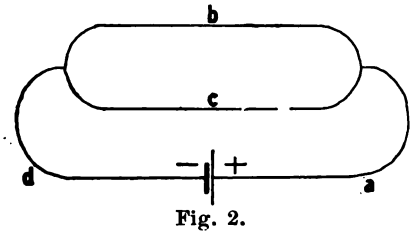


Fig. 2.

In considering the passage of a current through a circuit of this sort, it may be necessary to determine how much current will pass through one branch and how much through the other. Evidently this will depend upon the relative resistance of the two branches, and more current will pass through the branch offering the lesser resistance than through the branch having the higher

resistance. If the two parts have equal resistances, then one half of the total current will pass through each branch. If one branch has twice the resistance of the other, then only one-half as much of the total current will pass through that branch as through the other; that is, $\frac{1}{3}$ of the total current will pass through the first branch and the remaining $\frac{2}{3}$ will pass through the second.

The relative strength of current in the two branches will be inversely proportional to their resistances, or directly proportional to their conductances.

Suppose the resistance of one branch of a divided circuit is r_1 (see Fig. 3), and that of the other is r_2. Then by the preceding law,

$$\text{current in } r_1 : \text{current in } r_2 : : r_2 : r_1$$

Also,

$$\text{current in } r_1 : \text{total current} : : r_2 : r_1 + r_2$$

and

$$\text{current in } r_2 : \text{total current} : : r_1 : r_1 + r_2$$

Let I represent the total current, i_1 the current through the resistance r_1 and i_2 the current through the resistance r_2. Then the two preceding proportions are expressed by the following formulas:

$$i_1 = \frac{Ir_2}{r_1 + r_2} \quad \text{and} \quad i_2 = \frac{Ir_1}{r_1 + r_2}$$

Example.—The total current passing in a circuit is 24 amperes. The circuit divides into two branches having resistances of 5 and 7 ohms respectively. What is the current in each branch?

Solution.—In this case $I = 24$, $r_1 = 5$ and $r_2 = 7$. Substituting these values in the above formulas we have,

$$i_1 = \frac{Ir_2}{r_1 + r_2} = \frac{24 \times 7}{5 + 7} = 14 \text{ amperes.}$$

and

$$i_2 = \frac{Ir_1}{r_1 + r_2} = \frac{24 \times 5}{5 + 7} = 10 \text{ amperes.}$$

Ans. { In 5 ohm branch, 14 amperes. In 7 ohm branch, 10 amperes.

Joint Resistance of Divided Circuits. As a divided circuit

offers two paths to the current, it follows that the joint resistance of the two branches will be less than the resistance of either branch alone. The ability of a circuit to conduct electricity is represented by its conductance, which is the reciprocal of resistance; and the conductance of a divided circuit is equal to the sum of the conductances of its parts.

For example, in Fig. 3, the conductance of the upper branch equals $\frac{1}{r_1}$ and that of the lower branch equals $\frac{1}{r_2}$. If R represents the joint resistance of the two parts then the joint conductance equals:

$$\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2} = \frac{r_1 + r_2}{r_1 r_2}$$

Having thus obtained the joint conductance, the joint resistance is found by taking the reciprocal of the conductance, that is,

$$R = \frac{r_1 r_2}{r_1 + r_2}$$

This formula may be stated as follows:

The joint resistance of a divided circuit is equal to the product of the two separate resistances divided by their sum.

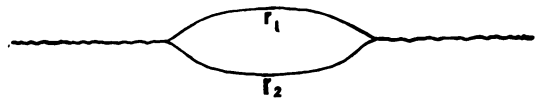


Fig. 3.

For example, suppose the resistance of each branch to be 2 ohms. The conductance of the circuit will be,

$$\frac{1}{R} = \frac{1}{2} + \frac{1}{2} = 1, \text{ and hence } R = 1 \text{ ohm.}$$

Also by the preceding formula,

$$R = \frac{2 \times 2}{2 + 2} = 1 \text{ ohm.}$$

The resistance of a divided circuit in which each branch has a resistance of 2 ohms is therefore 1 ohm.

Example.—The resistances of two separate conductors are 3

and 7 ohms respectively. What would be their joint resistance if connected in parallel?

Solution.—In this case $r_1 = 3$ and $r_2 = 7$, hence by the formula,

$$R = \frac{3 \times 7}{3 + 7} = 2.1 \text{ ohms.} \qquad \text{Ans. 2.1 ohms.}$$

Suppose, as illustrated in Fig. 4, the conductors having resistances equal to r_1, r_2 and r_3 respectively, are connected in

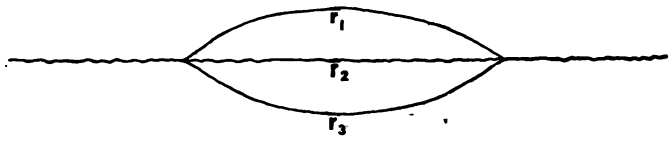


Fig. 4.

parallel. The joint total conductance will then be equal to,

$$\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} = \frac{r_2 r_3 + r_1 r_3 + r_1 r_2}{r_1 r_2 r_3}$$

and as the joint resistance is the reciprocal of the joint conductance, the joint resistance R of the three branches is expressed by the formula,

$$R = \frac{r_1 r_2 r_3}{r_2 r_3 + r_1 r_3 + r_1 r_2}$$

Example.—What is the joint resistance when connected in parallel, of three wires whose respective resistances are 41, 52 and 29 ohms respectively?

Solution. — In this case $r_1 = 41$, $r_2 = 52$ and $r_3 = 29$. Hence, by the preceding formula,

$$R = \frac{41 \times 52 \times 29}{52 \times 29 + 41 \times 29 + 41 \times 52} = 12.8 + \text{ohms.}$$

Ans. 12.8 + ohms.

In general, for any number of conductors connected in parallel, the joint resistance is found by taking the reciprocal of the sum of the reciprocals of the separate resistances.

Example.—A circuit is made up of five wires connected in parallel, and their separate resistances are respectively 12, 21, 28, 8 and 42 ohms. What is the joint resistance?

Solution.—The sum of the conductances is:

$$\frac{1}{12}+\frac{1}{21}+\frac{1}{28}+\frac{1}{8}+\frac{1}{42}=\frac{53}{168}$$

Hence the joint resistance equals:

$$R=\frac{168}{53}=3.1+\text{ ohms.} \qquad \text{Ans. } 3.1+\text{ ohms.}$$

If the resistance of each branch is known and also the potential difference between the points of union, then the current in each branch may be found by applying Ohm's law to each branch separately. For example, if this potential difference were 96 volts, and the separate resistances of the 4 branches were 8, 24, 3 and 48 ohms respectively, then the current in the respective branches would be 12, 4, 32 and 2 amperes respectively.

If the current in each branch is known and also the potential difference between the points of union, then the resistance of each branch may likewise be found from Ohm's law.

The following examples are given to illustrate the application of the preceding principles.

EXAMPLES FOR PRACTICE.

1. Two conductors having resistances of 71 and 19 ohms respectively are connected in parallel, and the total current passing in the circuit is 37 amperes. What current passes in the conductor whose resistance is 71 ohms? Ans. 7.8 + amperes.

2. What is the joint resistance of two wires connected in parallel if their separate resistances are 2 and 8 ohms respectively? Ans. 1.6 ohms.

3. What is the joint resistance of three wires when connected in parallel, whose separate resistances are 5, 7 and 9 ohms respectively? Ans. 2.2 + ohms.

4. Three wires, the respective resistances of which are 8, 10 and 20 ohms, are joined in parallel. What is their joint resistance? Ans. 3.6 + ohms.

5. Four wires are joined in parallel, and their separate resistances are 2, 4, 6 and 9 ohms respectively. What is the joint resistance of the conductor thus formed?

Ans. .97 + ohm.

Battery Circuits. Fig. 5 illustrates a simple circuit having a single cell C connected in series with a resistance. This is the customary manner of representing a cell, the short, heavy line representing the zinc and the long light line representing the copper or carbon plate. In determining the amount of current which will flow in such a circuit, the total resistance of the circuit must be considered. This is made up of the external resistance R and the internal resistance r, or the resistance of the cell itself. If E represents the total E. M. F. of the cell, then the current I which will flow is expressed by the formula,

$$I = \frac{E}{R + r}$$

It has been shown that whenever a current passes through any resistance, there is always a certain *drop* or fall of potential. The total E. M. F. above referred to, expresses the total potential difference between the plates of the cell and is the E. M. F. of the cell on *open* circuit. When the current flows, however, there is a fall of potential or loss of voltage within the cell itself, and hence the E. M. F. of the cell on closed circuit is less than on open circuit. That is, if the voltage be measured when the cell is supplying current, it will be found to be less than when the voltage is measured on open circuit, or when the cell is supplying no current. The voltage on closed circuit is that available for the external circuit, and is therefore called the *external* or *available* voltage or E. M. F.

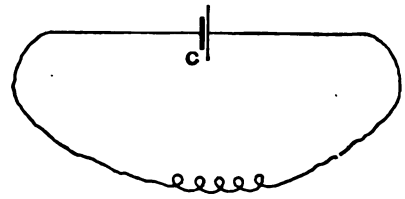


Fig. 5.

The external E. M. F. depends of course upon the strength of current the cell is supplying, and may be calculated as follows:

If the current passing is I and the resistance of the cell is r, then from Ohm's law the voltage lost in the cell equals $r\,I$. If E represents the total E. M. F. of the cell and E_1 the external E. M. F., then,

$$E_1 = E - r\,I$$

The E. M. F. of a cell is understood to be the total E. M. F. unless otherwise stated.

When two or more cells are interconnected they are said to form a *battery*.

Fig. 6 illustrates three cells connected in series with each other and with the external circuit. That is, the positive terminal of one cell is connected to the negative of the next, and the positive of that cell to the negative of the adjacent, etc. By this method of connecting, the E. M. F. of each cell is added to that of the others, so that the total E. M. F. of the circuit is three times that of a single cell. If one of the cells were connected so that its E. M. F. opposed that of the other two, it would offset the E. M. F. of one of the cells and the resultant E. M. F. would be that of a single cell. The connecting of cells in series as in Fig. 6 not only increases the E. M. F. of the circuit but also increases the internal resistance, the resistance of each cell being added to that of the others. If E equals the E. M. F. of each cell, r the internal resistance of each and R the external resistance, then the current that will flow is expressed by the formula,

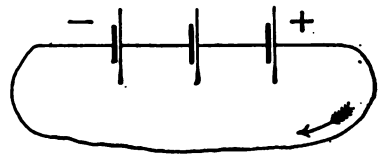


Fig. 6.

$$I = \frac{3E}{R + 3r}$$

or for n cells connected in series the formula for current is,

$$I = \frac{nE}{R + nr}$$

Fig. 7 illustrates two cells connected in parallel, and supplying current to an external circuit. Here the two positive terminals are connected with each other and also the two negative. The E. M. F. supplied to the circuit is equal to that of a single cell only. In fact connecting cells in parallel, is equivalent to enlarging the

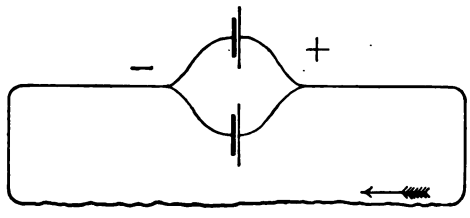


Fig. 7.

plates, and the only effect is to decrease the internal resistance. It is evident that coupling two cells in parallel affords two paths for the current and so decreases the resistance of the two cells to one-half that of a single cell. The formula expressing the current that would flow in the external circuit with two cells in parallel is therefore,

$$I = \frac{E}{R + \frac{r}{2}}$$

or for n cells connected in parallel, the formula for current is,

$$I = \frac{E}{R + \frac{r}{n}}$$

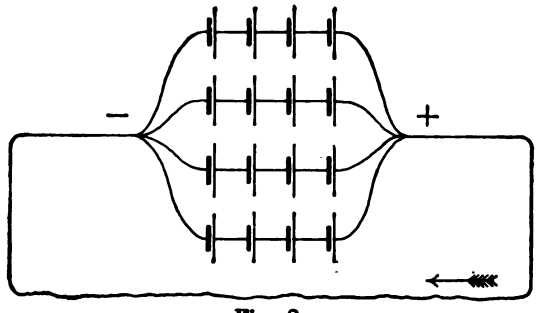


Fig. 8.

Fig. 8 represents a combination of the series and parallel method of connecting and represents four files of cells joined in parallel and each file having four cells connected in series. The E. M. F. of each file and consequently of the circuit is 4 E. The resistance of each file is 4 r and that of all the files $\frac{4\,r}{4}$. Hence, the formula for current is,

$$I = \frac{4\,E}{R + \frac{4\,r}{4}}$$

If there were n files connected in parallel and m cells were

connected in series in each file, the formula expressing the current in the external circuit would be,

$$I = \frac{m E}{R + \frac{m r}{n}}$$

where E is the E. M. F. of each cell, R the external resistance, and r the internal resistance of each cell.

The most advantageous method of connecting cells depends upon the results desired, the resistance of the cell and the external resistance. Suppose it is desired to pass a current through an external resistance of 2 ohms, and that Daniell's cells are to be used each having an E. M. F. of 1 volt and an internal resistance of 3 ohms.

With one cell only in circuit, the current will be,

$$\frac{E}{R + r} = \frac{1}{2 + 3} = .2 \text{ ampere,}$$

and with 5 cells all in series the current will be,

$$\frac{5 E}{R + 5 r} = \frac{5}{2 + 15} = .3 \text{ ampere (approx.).}$$

Therefore with 5 cells in series the current is only .1 ampere greater than with a single cell, and with 100 cells in series the current is only,

$$\frac{100 E}{R + 100 r} = \frac{100}{2 + 300} = .33 \text{ ampere.}$$

Hence with a comparatively low external resistance, there is but little gain in current strength by the addition of cells in series. This is due to the fact that, although the E. M. F. is increased 1 volt by each cell, the resistance is increased by 3 ohms.

Now suppose 5 Daniell cells to be connected in parallel with the external circuit of 2 ohms. The E. M. F. of the circuit will then be that of a single cell and the current will be,

$$\frac{E}{R + \frac{r}{5}} = \frac{1}{2 + \frac{3}{5}} = .4 \text{ ampere (nearly),}$$

and with 100 cells connected in parallel the current will be,

$$\frac{E}{R+\frac{r}{100}} = \frac{1}{2+\frac{3}{100}} = .5 \text{ ampere (nearly).}$$

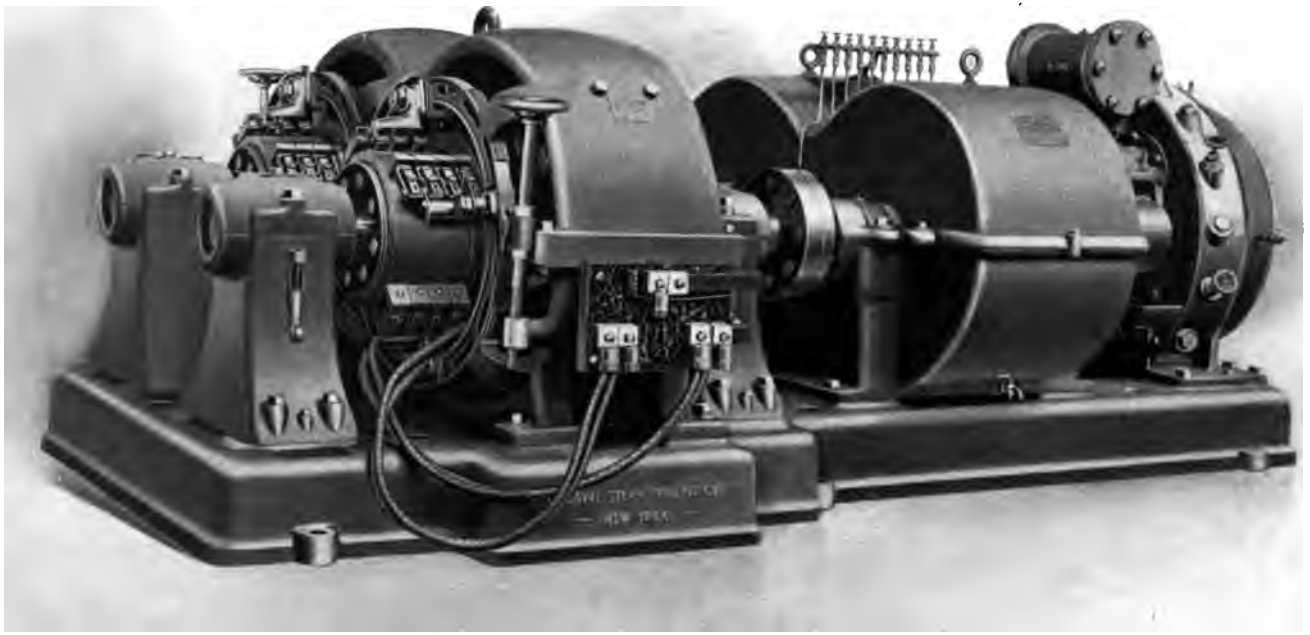
A larger current is therefore obtained in this case by connecting the cells in parallel than by connecting them in series.

With a large external resistance on the other hand, a larger current is obtained by connecting the cells in series. For example, suppose the external resistance to be 500 ohms. One cell will then give a current of .00198 + ampere, and 5 cells in series will give about .0097 ampere, whereas 100 cells will give .125 ampere. With 5 cells connected in parallel the current will be .00199 + ampere, and with 100 cells the current will amount to approximately .002 ampere. With an external resistance of 500 ohms, there is practically no advantage in connecting the cells in parallel. The only effect of the latter method is to decrease the internal resistance which is almost negligible in comparison with the external resistance.

It may be shown mathematically that for a given external resistance and a given number of cells, the largest current is obtained when the internal resistance is *equal* to the external resistance. In order to obtain this result the values of m and n in the formula on page 30, should be so chosen that $\frac{m\,r}{n}$ equals R. This arrangement, although giving the largest current strength, is not the most economical. With the internal resistance equal to the external resistance there is just as much energy used up in the battery itself as is expended usefully in the external circuit.

In order to obtain the most economical arrangement, the internal resistance should be made as small as possible, that is, all the cells should be connected in parallel. The loss of power in the battery is then the smallest amount possible.

In order to obtain the quickest action of the current the cells should be connected in series. When the external circuit possesses considerable self-induction, as is the case when electromagnets are connected in the circuit, the action of the current is retarded.



De Laval Steam Turbine Dynamo, 300 H. P., 200 K. W., Direct Current.

internal resistance equals the external resistance or when

$$\frac{m\,r}{n} = R.$$

With 5 files and 4 cells in series,

$$\frac{m\,r}{n} = \frac{4 \times 3.8}{5} = 3.04 \text{ ohms,}$$

and with 4 files and 5 cells in series,

$$\frac{m\,r}{n} = \frac{5 \times 3.8}{4} = 4.75 \text{ ohms.}$$

The latter value is nearer to 4 ohms, which is the external resistance, than is 3.04, hence the larger current will be supplied with 4 files and 5 cells in series. Ans. 4 files, with 5 cells in series.

Example.—It is desired to pass a current of .025 ampere through an external resistance of 921 ohms. The cells are to be connected in series and each has an E. M. F. of .8 volt and an internal resistance of 1.3 ohms. What number of cells must be used?

Solution.—From page 28, the general formula for cells in series is,

$$I = \frac{nE}{R + n\,r}$$

and in this case $I = .025$, $E = .8$, $R = 921$ and $r = 1.3$. Substituting these values gives,

$$.025 = \frac{n\,.8}{921 + n\,1.3}$$

Multiplying by $921 + 1.3\,n$ gives

$$23.025 + .0325\,n = .8\,n$$

Transposing $.0325\,n$ gives

$$.8\,n - .0325\,n = 23.025$$

or

$$.7675\,n = 23.025$$

hence,

$$n = 30$$

Ans. 30 cells.

EXAMPLES FOR PRACTICE.

1. Ten cells in series have an E. M. F. of 1 volt each and

an internal resistance of .2 ohm. The external resistance is 3 ohms. What is the current? Ans. 2 amperes.

2. Six cells, each of which has an E. M. F. of 1.2 volts and a resistance of 2 ohms, are connected in parallel. With an external resistance of 10 ohms, what is the current? Ans. .116 + ampere.

3. What is the current supplied by the same cells if joined in series and the external resistance is 20 ohms?

Ans. .225 ampere.

4. A single cell whose E. M. F. on open circuit is 1.41 volts and whose internal resistance is .5 ohm is supplying a current of .3 ampere. What is the available E. M. F. of the cell?

Ans. 1.26 volts.

5. What would be the available E. M. F. with 8 of the cells referred to in example 4, when connected in series and supplying the same current? Ans. 10.08 volts.

6. Eight Daniell cells (E. M. F. = 1.05, resistance = 2.5 ohms each) are joined in series. Three wires A, B and C of 9, 36 and 72 ohms resistance respectively are arranged to be connected to the poles of the battery. Find the current when each wire is inserted separately, and when all three wires are connected in parallel.

Ans. Through A, .29 ampere nearly; through B, .15 ampere; through C, .091 + ampere; and through all three, .31 + ampere.

7. A battery of 28 Bunsen cells (E. M. F. = 1.8, resistance = .1 ohm each) are to supply current to a circuit having an external resistance of 30 ohms. Find the current (*a*) when all the cells are joined in series, (*b*) when all the cells are in parallel, (*c*) when there are 2 files each having 14 cells in series, (*d*) when there are 7 files each having 4 cells in series.

Ans. (*a*) 1.53 +; (*b*) .06 nearly; (*c*) .82 +; (*d*) .23 + ampere.

QUANTITY, ENERGY AND POWER.

Quantity. The strength of a current is determined by the amount of electricity which passes any cross section of the conductor in a second; that is, current strength expresses the *rate* at which electricity is conducted. The *quantity* of electricity conveyed evidently depends upon the current strength and the time the current continues.

The Coulomb. The coulomb is the unit of quantity and is equal to the amount of electricity which passes any cross-section of the conductor in one second when the current strength is one ampere. If a current of one ampere flows for two seconds, the quantity of electricity delivered is two coulombs, and if two amperes flow for one second the quantity is also two coulombs. With a current of four amperes flowing for three seconds, the quantity delivered is 12 coulombs. The quantity of electricity in coulombs is therefore equal to the current strength in amperes multiplied by the time in seconds, or

$$Q = I \times t$$

where Q is the quantity in coulombs, I the current in amperes and t the time in seconds.

The coulomb is also called the *ampere-second*. The quantity of electricity delivered in one hour when the current is one ampere is called one *ampere-hour*. The ampere-hour is equal to 3,600 coulombs, as it is equal to one ampere for 3,600 seconds.

From the formula $Q = It$, it follows that

$$I = \frac{Q}{t} \text{ and } t = \frac{Q}{I}$$

Example.—A current of 18 amperes flows through a circuit for $2\frac{1}{4}$ hours. What quantity of electricity is delivered?

Solution.—Reducing $2\frac{1}{4}$ hours to seconds gives 8,100 seconds, and $8{,}100 \times 18 = 145{,}800$. Ans. 145,800 coulombs.

Example.—What is the strength of current when $1\frac{1}{2}$ ampere-hours pass in a circuit in 89 seconds?

Solution.—One and one-half ampere-hours equal 5,400 coulombs and as current strength is expressed by quantity divided by time, the current is $5{,}400 \div 89 = 60.+$ amperes.

Ans. $60.+$ amperes.

EXAMPLES FOR PRACTICE.

1. How many coulombs are delivered in 9 minutes, when the current is $17\frac{1}{2}$ amperes? Ans. 9,450 coulombs.

2. What is the current when 480 coulombs are deliverec per minute? Ans. 8 amperes.

3. In what time will 72,000 coulombs be delivered when the current is 80 amperes? Ans. 15 minutes.

4. How many ampere-hours pass in a circuit in $2\frac{3}{4}$ hours when the current is 22 amperes? Ans. 60.5 ampere-hours.

Energy. Whenever a current flows, a certain amount of energy is expended, and this may be transformed into heat, or mechanical work, or may produce chemical changes. The unit of mechanical energy is the amount of work performed in raising a mass of one pound through a distance of one foot, and is called the foot-pound. The work done in raising any mass through any height, is found by multiplying the number of pounds in that mass by the number of feet through which it is lifted. Electrical work may be determined in a corresponding manner by the amount of electricity transferred through a difference of potential.

The Joule. The joule is the unit of electrical energy, and is the work performed in transferring one coulomb through a difference of potential of one volt. That is, the unit of electrical energy is equal to the work performed in transferring a unit quantity of electricity through a unit difference of potential. It is evident that if 2 coulombs pass in a circuit and the difference of potential is one volt, the energy expended is 2 joules. Likewise if 1 coulomb passes and the potential difference is 2 volts, then the energy expended is also 2 joules. Therefore, to find the number of joules expended in a circuit, multiply the quantity of electricity by the potential difference through which it is transferred. This is expressed by the formula,

$$W = Q\ E, \text{ or } W = I\ E\ t,$$

where W is the work in joules, Q the quantity in coulombs, E the potential difference in volts, I the current in amperes and t the time in seconds.

By Ohm's law $E = R\ I$ and by substituting this value of E in the equation for energy, we obtain the formula,

$$W = I^2\ R\ t,$$

which may be used when the current, resistance, and time are known, R being the resistance in ohms.

Example.—With a potential difference of 97 volts and a current of 14 amperes, what energy is expended in 20 minutes?

Solution.—Work is expressed by the product of the quantity

and potential difference. The time in seconds equals $20 \times 60 = 1200$, and the work $W = 14 \times 1200 \times 97 = 1{,}629{,}600$ joules.

Ans. 1,629,600 joules.

Example. — The resistance of a circuit is .9 ohm, and the current is 25 amperes. What energy is expended in half an hour?

Solution.— Substituting these values of resistance, current and time in the formula $W = I^2 R t$, we have, $W = 25^2 \times .9 \times 30 \times 60 = 1{,}012{,}500$ joules. Ans. 1,012,500 joules.

Power. Power is the *rate* of doing work, and expresses the amount of work done in a certain time. The horse-power is the unit of mechanical energy, and is equal to 33,000 foot-pounds per minute or 550 foot-pounds per second. A certain amount of work may be done in one hour or two hours, and in stating the work done to be so many foot-pounds or so many joules, the rate at which the work is done is not expressed. Power on the other hand, includes the rate of working.

It is evident that if it is known that a certain amount of work is done in a certain time, the rate at which the work is done, or the power, may be obtained by dividing the work by the time, giving the work done per unit of time.

The Watt. The electrical unit of power is the watt, and is equal to one joule per second, that is, when one joule of work is expended in one second, the power is one watt. If the number of joules expended in a certain time is known, then the power in watts is obtained by dividing the number of joules by the time in seconds. The formulas for the work done in joules as given on the preceding pages are,

$$W = I E t, \text{ and } W = I^2 R t.$$

By dividing each of these by the time t, we obtain the corresponding formulas for power as follows:

$P = I E$, and $P = I^2 R$, where P is the power in watts, I the current in amperes, E the potential difference in volts, and R the resistance in ohms.

The power is obtained therefore, by multiplying the current by the voltage, or by multiplying the square of the current by the resistance.

The watt is sometimes called the *volt-ampere.*

For large units the *kilowatt* is used, and this is equal to 1,000

watts. The common abbreviation for kilowatt is K. W. The *kilowatt-hour* is a unit of energy, and is the energy expended in one hour when the power is one kilowatt.

EXAMPLES FOR PRACTICE.

1. A current of 40 amperes is supplied to a circuit and the voltage is 110. What is the power in watts? Ans. 4400 watts.

2. What is the power in kilowatts supplied to a number of incandescent lamps when the current is 84 amperes and the voltage of the circuit 97? Ans. 8.1+ kilowatts.

3. A circuit has a resistance of 50 ohms and the current is 12 amperes. What power is expended in the circuit?

Ans. 7.2 K. W.

4. The voltage of an incandescent lamp circuit is 220 volts, and the resistance 2 ohms. What power is expended in the circuit? Ans. 24.2 K. W.

NOTE. — First find current by Ohm's law.

Equivalence of Electrical Energy in Heat Units. Whenever there is any resistance to the flow of a current there is always a certain amount of electrical energy transformed into heat. The current in passing through such resistance expends a certain amount of energy in overcoming the resistance, and this energy is dissipated as heat. The entire electrical energy of a circuit may be transformed into heat, as in a lamp circuit, or only part of the energy may appear as heat, the remainder being transformed into mechanical or chemical work. The energy which appears as heat raises the temperature of the circuit to an amount depending upon its radiating surface, and the temperature of the surrounding medium.

When the resistance of a circuit and the current are known, the electrical energy expended may be calculated by finding the product of the square of the current, the resistance, and the time, as by the formula at the foot of page 36. All this energy is transformed into heat. Other work may be done by the current, as would be the case if an electric motor were connected to the circuit, but this requires additional energy to that which is dissipated as heat. The formula referred to gives only the energy lost as heat, which is the total energy when no other work is done.

This formula, which gives the energy in joules, is in accordance with Joule's law, which is as follows:

The number of heat units developed in a conductor is proportional to its resistance, to the square of the current, and to the time the current lasts.

As we have seen, the unit of electrical energy is the joule. The common unit of heat is the calorie, which is the amount of heat necessary to raise the temperature of 1 gram of water through 1 degree Centigrade. By careful investigations it has been found that the joule is equivalent to .24 of a calorie; that is, one joule of electrical energy when transformed into heat is equal to .24 calorie. Electrical energy may therefore be expressed in heat units by multiplying the number of joules by .24; that is,

$$U = I^2 \times R \times t \times .24$$

where U is the heat in calories.

As one joule is equivalent to .24 calorie, it follows that one calorie is equivalent to 4.2 joules approximately.

EXAMPLES FOR PRACTICE.

1. How many calories will be developed by a current of 30 amperes flowing through a resistance of 12 ohms for 10 seconds?

Ans. 25,920 calories.

2. What amount of heat will a current of 20 amperes develop if it flows through a resistance of 80 ohms for 2 seconds?

Ans. 15,360 calories.

Equivalent of Electrical Energy in Mechanical Units. The common unit of mechanical energy is the foot-pound, and from experiment it has been found that one joule is equivalent to .7373 foot-pound; that is, the same amount of heat will be developed by one joule as by .7373 foot-pound of work.

As one horse-power is equal to 550 foot-pounds per second, it follows that this rate of working is equivalent to

$$\frac{550}{.7373} = 746 \text{ joules per second (approx.)}.$$

Hence one horse-power is equivalent to 746 watts. Therefore to find the equivalent of mechanical power in electrical power multiply the horse-power by 746, and to find the equiva-

lent of electrical power in mechanical power divide the number of watts by 746.

EXAMPLES FOR PRACTICE.

1. A power of 287 watts is equivalent to how many horse-power? Ans. .38+ H. P.

2. The voltage applied to a circuit is 500 and the current is 196 amperes. What is the equivalent horse-power of the circuit? Ans. 131+ H. P.

3. What is the equivalent of 43 H. P. in kilowatts? Ans. 32+ K. W.

4. How many horse-power approximately are equivalent to one kilowatt? Ans. $1\frac{1}{3}$ H. P.

THE SUPPLY OF ELECTRICAL ENERGY.

Electrical energy is now made use of on such a large scale for lighting, power, heating, etc., that it is generated or produced by machines of great capacity. The dynamo is used for this purpose and machines having a capacity of several thousand kilowatts are now common.

Central Stations. Large central stations or power houses are built at convenient places and here are collected the generating, controlling and measuring apparatus. Usually steam engines or turbines are used to drive the dynamos, and from the latter, large copper mains conduct the current to the switchboard located within the station. Here are assembled all the regulating devices, instruments, and switches for the control of the system. From the switchboard conducting mains run out to various distant points, where the energy is to be used, to the receiving apparatus, such as electric motors, lamps, heating devices, etc. A complete system is therefore made up of three sub-divisions — the generating plant, the conducting mains, and the receiving apparatus.

Isolated Plants. Besides large central stations which occupy one or more entire buildings and which are usually built and designed especially for such purpose, there are the comparatively small and simple plants called isolated power plants. They are purely local systems and supply energy to a single building, or to buildings in the immediate vicinity. The generating apparatus in this case is usually located in the basement of the building.

Large hotels and office buildings are frequently provided with individual generating plants.

Losses in Energy. In operating an electrical machine there is always some loss in energy, that is, the machine does not give out an amount of energy equivalent to the amount it receives. Besides ordinary mechanical losses there is in addition the electrical loss, which always occurs when a current flows through any resistance. This loss as previously explained, is equal to the square of the current multiplied by the resistance.

The ratio of the amount of energy which a machine gives out, to the amount which it receives is called the **commercial efficiency** of the machine. For example, if the commercial efficiency of a dynamo is stated to be 80%, then 20% of the energy given to the dynamo is lost, partly in overcoming friction and partly in electrical losses.

Where electricity is transmitted some distance by means of conducting mains, there takes place a loss in the line due to heating, which is frequently as much as 10%. Also at the receiving station, if the electrical energy is converted into mechanical by means of an electric motor, there will be a further loss.

Illustrative Example. For example, suppose it is desired to ascertain the losses in a system which comprises a generator, conducting mains and an electric motor. Suppose the efficiency of the generator is 92% and that 1000 horse-power are imparted to it by the driving engine. The output of the dynamo will be $.92 \times 1000$, or 920 horse-power, and this is equivalent to 920×746, or 686,320 watts. The energy lost in the dynamo will be 80×746, or 59,680 watts. We will assume the voltage of the dynamo and the circuit to be 1000, and as the power in watts is equal to the product of the voltage and current, the current must be $686{,}320 \div 1000$, or 686 amperes approximately.

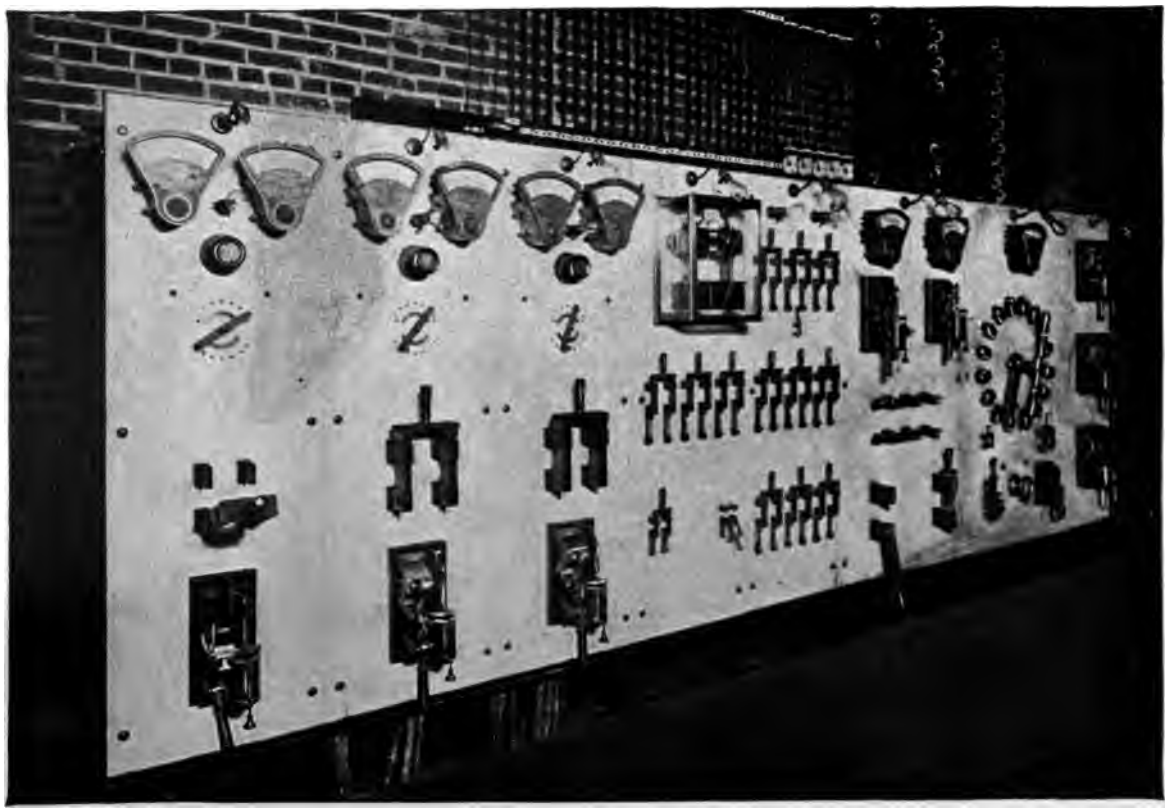
Now suppose the resistance of the conducting mains is equal to .11 ohms. Knowing the current in the mains and the resistance, the loss therein is obtained by applying the formula $I^2 R$ giving $686^2 \times .11$, or 51,765 watts. The energy available at the receiving end of the line will therefore be $686{,}320 - 51{,}765$, or 634,555 watts.

The remaining loss to be considered is that in the electric

motor. Assuming the efficiency of the motor to be 90%, the power lost therein will be .10 × 634,555, or 63,455 watts. The output of the motor is therefore equivalent to 634,555 — 63,455, or 571,100 watts. This in mechanical units is equal to 571,100 ÷ 746, or 765 horse-power approximately.

Hence from an input of 1,000 horse-power at the generating station, the work the motor is capable of performing at the receiving station is 765 horse-power. The efficiency of the entire system under the assumed conditions is therefore 765 ÷ 1,000, or 76.5 %.

Among the great variety of generating machines, systems of distribution and auxiliary devices, each has its particular advantage for special conditions, and the selection of the type of machine and system of distribution depends almost entirely upon the special circumstances. For example, a low voltage system is best adapted for isolated plants, whereas for the transmission of power long distances very high voltages are used. The various types of machines, systems, etc., with their special advantages and disadvantages will be fully considered in the following Instruction Papers.



Switchboard for Lighting and Elevators in Connection with "Chloride Accumulators."

ELECTRIC WIRING.

INSTALLING THE DYNAMO.

Dynamos should be located in a dry place so situated that the surrounding atmosphere is cool. If the surrounding air is warm, it reduces the safe carrying capacity of the machine and is likely to allow such temperature to rise in the machine itself as to burn out either armature or field, or both. A dynamo should not be installed where any hazardous process is carried on, nor where it would be exposed to inflammable gases or flying combustible materials, as the liability to occasional sparks from the commutator or brushes might cause serious explosions.

Wherever it is possible, dynamos should be raised or insulated above the surrounding floor, on wooden base frames, which should be kept filled to prevent the absorption of moisture, and also kept clean and dry. When it is impracticable to insulate a dynamo on account of its great weight, or for any other reason, the Inspection Department of the Board of Fire Underwriters having jurisdiction may, in writing, permit the omission of the wooden base frame, in which case the frame should be permanently and effectively grounded. When a frame is grounded, the insulation of the entire system depends upon the insulation of the dynamo conductors from the frame, and if this breaks down the system is grounded and should be remedied at once.

Grounding Dynamo Frames can be effectually done by firmly attaching a wire to the frame and to any main water pipe inside the building. The wire should be securely fastened to the pipe by screwing a brass plug into the pipe and soldering the wire to this plug. When the dynamo is direct driven, an excellent ground is obtained through the engine coupling and the piping of the engine and boiler.

Wherever high-potential machines have their frames grounded, a small board walk should be built around them and raised above the floor, on porcelain or glass insulators, in order that the

dynamo tender may be protected from a shock when adjusting brushes or working about the machine.

Sufficient space should be left on all sides of the dynamo and especially at the commutator end, so that there may be ample room for removing armatures, commutators, or any other parts at any time.

Circuit Breakers and Fuses. Every constant-potential generator should be protected from excessive current by a safety fuse or equivalent device of approved design, in each wire lead, such as a circuit breaker. The latter is preferable, on account of its being immeasurably more accurate and convenient for resetting. Such devices should be placed on or as near as possible to the dynamo. When the needs of the service make these devices impracticable, the Inspection Department having jurisdiction may, in writing, modify the requirements.

The best practice is to place the fuses on the dynamo itself, and the circuit breakers on the switchboard.

Waterproof Covers should be provided for every dynamo and placed over each machine as soon as it is shut down. Negligence in this matter has caused many an armature and field coil to burn out, as only a few drops of water are necessary to cause a short circuit as soon as the machine is started up again, which might do many dollars' worth of damage, to say nothing of the inconvenience caused by shutting off light or power when it is most needed, and for an indefinite length of time.

Name-Plates. Every dynamo should be provided with a name-plate, giving the maker's name, the capacity in volts and amperes, and the normal speed in revolutions per minute. This will show exactly what the machine was designed for, and how it should be run.

Wiring from Dynamos to switchboards should be in plain sight or readily accessible, and should be supported entirely upon non-combustible insulators, such as glass or porcelain; in no case should any wire come in contact with anything except these insulators, and the terminals upon the dynamos and switchboards. When it becomes necessary to run these wires through a wall or floor, the holes must be protected by some approved non-combus-

tible insulating tube, such as glass or porcelain, and in every case the tube must be fastened so that it shall not slip or pull out. Sections of any tubing, whether armored or otherwise, that are chopped off for this purpose, should not be used. All wires for dynamos and switchboard work should be kept so far apart that there is no liability of their coming in contact with one another, and should be covered with non-inflammable insulating material sufficient to prevent accidental contact, except that bus bars may be made of bare metal so that additional circuits can be readily attached. Wires must have ample carrying capacity, so as not to heat with the maximum current likely to flow through them under natural conditions. (See "Capacity of Wires Table," page 37.) So much trouble in past years has arisen from faulty construction of switchboards, and the apparatus placed upon them, that strict requirements have been necessarily adopted by engineers as well as insurance inspectors, and the following suggestions are recommended by the latter:

The Switchboard should be so placed as to reduce to a minimum the danger of communicating fire to adjacent combustible material, and, like the dynamo, should be erected in a dry place and kept free from moisture. It is necessary that it should be accessible from all sides when the wiring is done on the back of the board, but it may be placed against a brick or stone wall when all wiring is on the face.

The board should be constructed wholly of non-combustible material, but when this is impossible a hard-wood board made in skeleton form, and well filled to prevent absorption of moisture, is considered safe. Every instrument, switch or apparatus of any kind placed upon the switchboard should have its own non-combustible insulating base. This is required of every piece of apparatus connected in any way with any circuit. If it is found impossible to place the resistance box or regulator (which should, in every case, be made entirely of non-combustible material) upon the switchboard, it must be placed at least one foot from combustible material or separated therefrom by a non-inflammable, non-absorptive insulating material. A slate slab is preferable. Special attention is called to the fact that switchboards should not

be built down to the floor, nor up to the ceiling, but a space of at least ten or twelve inches should be left between the floor and the board, and from eighteen to twenty-four inches between the ceiling and the board, in order to prevent fire from communicating from the switchboard to the floor or ceiling, and also to prevent space being used for storage of rubbish and oily waste.

Lightning Arresters should be attached to each side of every overhead circuit connected with the station.

It is recommended to all electric light and power companies that arresters be connected at intervals over systems in such numbers and so located as to prevent ordinary discharges entering (over the wires) buildings connected to the lines. They should be located in readily accessible places away from combustible materials, and as near as practicable to the point where the wires enter the building.

Station arresters should generally be placed in plain sight on the switchboard. In all cases, kinks, coils and sharp bends in the wires between the arresters and the outdoor lines should be avoided as far as possible. Arresters should be connected with a thoroughly good and permanent ground connection by metallic strips or wires having a conductivity not less than that of a No. 6 B. & S. copper wire, and running as nearly as possible in a straight line from the arresters to the earth connection.

Ground wires for lightning arresters should not be attached to gas pipes within the buildings.

It is often desirable to introduce a choke coil in circuit between the arresters and the dynamo. In no case should the ground wire from a lightning arrester be put into iron pipes, as these would tend to impede the discharge.

Unless a good, damp ground is used in connection with all lightning arresters, they are practically useless. Ground connections should be of the most approved construction, and should be made where permanently damp earth can be conveniently reached. For a bank of arresters such as is commonly found in a power house, the following instructions will be found valuable: First, dig a hole six feet square directly under the arresters, until permanently damp earth has been reached; second, cover the bot-

tom of this hole with two feet of crushed coke or charcoal (about pea size); third, over this lay twenty-five square feet of No. 16 copper plate; fourth, solder at least two ground wires, which should not be smaller than No. 6, securely across the entire surface of the ground plate; fifth, now cover the ground plate with two feet of crushed coke or charcoal; sixth, fill in the hole with earth, using running water to settle.

All lightning arresters should be mounted on non-combustible bases and be so constructed as not to maintain an arc after the discharge has passed; they should have no moving parts.

Testing of Insulation Resistance. All circuits except those permanently grounded should be provided with reliable ground detectors. Detectors which indicate continuously and give an instant and permanent indication of a ground are preferable. Ground wires from detectors should not be attached to gas pipes within the building.

Where continuously indicating detectors are not feasible, the circuits should be tested at least once per day.

Data obtained from all tests should be preserved for examination.

Storage or Secondary Batteries should be installed with as much care as dynamos, and in wiring to and from them the same precautions and rules should be adopted for safety and the prevention of leaks. The room in which they are placed should be kept not only dry, but exceptionally well aired, to carry off all fumes which are bound to arise. The insulators for the support of the secondary batteries should be glass or porcelain, as filled wood alone would not be approved.

Care of Dynamos. A few suggestions as to the care of the dynamo, as well as its installation, may be of value; and one of the important points under this head is that the driving power should have characteristics of steadiness and regularity of speed, and should always be sufficient to drive the dynamo with its full load, besides doing the other work which it may be called upon to sustain. Unsatisfactory results are always obtained by attempting to run a dynamo on an overloaded engine.

Wooden bed-plates are supplied, when ordered, for all dynamos, except in the largest and direct-connected machines.

Most machines are fitted with a ratchet and screw bolt, so that they may be moved backward or forward on the bed-plate in a direction at right angles to the armature shaft. By this means the driving belt can be tightened or loosened at will, while the machine is in operation. Care should be taken in tightening the belt not to bind the bearings of the armature and force the oil from between the surfaces of the shaft and boxes. Such practice will inevitably cause heating of the bearings and consequent injury.

Machines are usually assembled, unless ordered otherwise, so that the armature revolves clock-wise when the observer faces the pulley end of the shaft. All bipolar dynamos, however, may be driven in either direction by reversing the brushes and changing field connections.

The machine is provided with a pulley of the proper size to transmit the power demanded, and a smaller one should not be substituted unless approval be obtained from the makers.

When driving from a countershaft, or when belted directly to the main shaft, a loose pulley or belt holder should be used, to admit of starting and stopping the dynamo while the shafting is running.

Belts. A thin double or heavy single belt should be used, about a half inch narrower than the face of the pulley on the dynamo. An endless belt, one without lacing, gives the greatest steadiness to the lights.

All bolts and nuts should be firmly screwed down. All nuts which form part of electrical connections should receive special attention.

The copper commutator brushes are carefully ground to fit the commutator, and they should be set in the holders so as to bear evenly upon its surface. On machines where two or more brushes are supported on one spindle, the brushes on the same side of the commutator must be set so that they touch the same segments in the same manner. The brushes on the other side of the commutator must be set to bear on the segments diametrically

opposite. When the brushes are not so set it is impossible to run the machine without sparking. A convenient method of determining the proper bearing point for the brushes is to set the toe of one brush at the line of insulation, dividing two segments of the commutator; then count the dividing lines for one-half the way around the surface, and set the other brush or brushes at the line diametrically opposite the first. Thus, on the forty-four segment commutator, after setting the tip of one brush at a line of insulation, count around twenty-three lines, setting the other brush at the twenty-third line, thus bringing the tips directly opposite each other. The angle which the brushes form with the surface of the commutator should be carefully noted, and the brushes should not be allowed to wear so as to increase or decrease this angle. Careless handling of the machine is at once indicated by the brushes being worn either to a nearly square end, or to a long taper in which the forward wires of the brush far outrun the back or inside wires. Either condition will inevitably be attended with excessive wear of both commutator and brushes.

After copper brushes are set in contact with the commutator, the armature should never be rotated backward. If it is required to turn the armature back, raise the brushes from the commutator by the thumb screw on the holder provided for that purpose, before allowing such rotation. When starting a machine, it is always better to let the brushes down upon the commutator after the machine has started, rather than before, except when carbon brushes are used.

Bearings. See that the bearings of the machine are clean and free from grit, and that the oil reservoirs are filled with a good quality of lubricating oil. The oil reservoirs should always be examined before starting, and all loose grit removed. After starting the machine, the oil should be all drawn off at the end of each day's run for the first three or four days, after which it may be assumed that any remaining grit has been carried off with the oil, and it will only be necessary to add a little fresh oil once in seven or ten days.

Starting Up a Dynamo or Motor. Fill the oil reservoirs and see that the automatic oiling rings are free to move. In the

case of dynamos fitted with oil cups, start the oil running at a moderate rate. Too little oil will result in heating and injury of the bearings, but, on the other hand, excessive lubrication is unnecessary, wasteful and sometimes productive of harm.

When the dynamo is ready to be started, place the driving belt on the pulley on the armature shaft, and then slip it from the loose pulley or belt holder on to the driving pulley on the countershaft. Tighten the belt by means of the ratchet on the bed-plate, just sufficiently to keep it from slipping. Care should be taken not to put more pressure than is necessary on new bearings; carelessness in this respect is often followed by heating of the boxes, and possible permanent injury.

The brushes may now be let down upon the commutator, and the magnets will be slowly energized. Move the brushes slowly backward or forward by means of the yoke handle until there is no sparking at the lower brushes. Clamp the yoke in this position. If the top brushes then spark, move them slightly, one at a time, forward or backward in the brush holder until their non-sparking point is found.

The spring pressure exerted upon the commutator brushes should be just sufficient to produce a good contact without causing cutting. If the brushes cut, the commutator must be smoothed by the use of sandpaper, not *emery cloth.*

The dynamo should run without load, at the speed given by the manufacturer, and this speed should be uniformly maintained under all conditions. In the case of incandescent dynamos, any increase of speed above that given, shortens the life of the lamps, while a variation below causes unsatisfactory lights.

Before the load is put on, the dynamo should be tested for polarity. This can be done by holding a small pocket compass near the field or pole piece. If the dynamo is connected to be run in multiple with another machine and happens to be polarized wrong, it can be given the right polarity by lifting the brushes from the commutator, closing the field switch and then closing the double-pole switch used to throw it in multiple with the other machine, which is supposed to be now running. After the current has been allowed to pass through the fields for a few moments,

the double-pole switch can be thrown open, and if a test with the compass is again made the polarity will be found to be right, and the dynamo is ready to be started in the usual manner.

In starting for the first time a bipolar dynamo which is to be run in multiple with a spherical armature dynamo, the above instructions should always be followed.

If the dynamo is to be used in series with another on the three-wire system, and is found to be polarized wrong, it can be given the right polarity by making a temporary connection from the positive brush of the new machine to the positive brush of the machine already in operation; and also a temporary connection from negative brush to negative brush, having first raised the brushes from the commutator and closed the field switch. Keep this connection for a few minutes, then open the field switch and break the temporary connections.

Another test with the compass will show that the polarity of the machine is now correct, and the dynamo is ready to be started in the usual manner.

Assuming that the lamps and lines are all ready, the following precautions must be observed when starting the dynamo:

Be very careful that the brushes are properly set and diametrically opposite each other, as explained before.

Be sure that all connections are securely made, and all nuts on the connection boards firmly set.

In cases where two or more dynamos are connected in multiple by the use of the equalizing connection, care should be taken that the circuit wires from both positive brushes are connected to the same side of the main line, while those from the negative are connected to the other side.

A neat arrangement of the equalizing connection can be made by using triple-pole switches on the switchboard, instead of double-pole switches, and making the equalizing connections through the center pole of the switch, instead of running a cable direct from one dynamo to the other. This method is especially desirable where three or more dynamos are run in multiple.

When dynamos are connected in series, as in the cases where the three-wire system is in use, the leading wire from the positive

brush of one machine is connected to the negative brush of the other. The other two brushes (negative and positive) are connected to the main wire on the outside of the system, while the third or center wire is connected to the conductor between the two dynamos.

Dust or Gritty Substances. All insulations should be carefully cleaned at least once a day.

If any of the connections of the machine become heated, examination will show that the metal surfaces are not clean or not in perfect contact. Avoid the use of water or ice on the bearings in case of accidental heating, as the water may get to the armature and injure the insulation.

The Commutator should be kept clean and allowed to polish or glaze itself while running. No oil is necessary, unless the brushes cut, and then only at the point of cutting. A cloth slightly greased with vaseline is best for the purpose. Never use sandpaper on the commutator without first lifting the brushes. Otherwise the grit will stick to the brushes and cut the commutator.

Brushes. Care should be taken to keep copper commutator brushes in good shape, and not to allow them to be worn out of square; that is, too much to one side, so that the end is not worn at right angles to the lateral edges.

When the machine is not running, the brushes should always be raised from the commutator. The brushes should be kept carefully cleaned, and no oil or dirt allowed to accumulate upon them. This can be done by washing them occasionally in benzine or in a hot solution of soda ash.

Manufacturers usually furnish a gauge, which should be used occasionally to test the wearing of the brushes. If they are found to be worn either too flat or too blunt, they should be filed in proper shape, or, better still, ground on a grindstone. Carbon brushes require less care. Spindles upon which the brush holders are arranged to slide should be cleaned with emery cloth often enough to prevent tarnishing or the collection of dirt, which might cause heating by impairing the electrical connection.

Brush holders that can be moved laterally on the spindle by

which they are supported, should be so arranged that the top and bottom brushes will bear on different parts of the length of the commutator, for the purpose of distributing the wear more uniformly.

In case of a **hot box** the most natural thing to do is to shut the machine down, but this should never be done until the following alternatives have been tried and failed:

First—Lighten the load.

Second—Slacken the belt.

Third—Loosen the caps on the boxes a little.

Fourth—Put more oil in bearings.

Fifth—If all the above fail to remedy the heating, use a heavy lubricant, such as vaseline or cylinder oil. Should the heating then diminish, the shaft must be polished with crocus cloth and the boxes scraped at the end of the day.

Sixth—Under no conditions put ice upon the bearing, unless you are perfectly familiar with such a procedure.

Seventh—If it is absolutely necessary to shut down, get the belt off as soon as possible, keeping the machine revolving meanwhile in order to prevent sticking, and at the same time take off the caps of the bearings. Do not stop the flow of oil to the bearings. When the caps have been taken off, stop the machine and get the linings out immediately, and allow them to cool in the air. Do not throw the linings into cold water, as it is liable to spring them.

Scraping should be done only by an experienced person, otherwise the linings may be ruined. Polish the shaft with crocus cloth, or, if badly cut, file with a very fine file, and afterwards polish with crocus.

Wipe the shaft, as well as the boxes, very carefully, as perhaps grit has been the cause of the hot box. Inspect the bearings; see that they are in line, that the shaft has not been sprung, and that the oil collar does not bear against the box.

Oily Waste should be kept in approved metal cans (made entirely of metal, with legs raising them at least three inches above the floor and with self-closing covers), and removed daily.

A competent man should always be kept on duty where generators are operating.

THE INSTALLATION OF MOTORS.

All motors should be insulated on floors or base frames, which should be kept filled to prevent absorption of moisture; also they should be kept clean and dry. Where frame insulation is impracticable, the Inspection Department having jurisdiction may, in writing, permit its omission, in which case the frame should be permanently and effectively grounded.

A high-potential machine which on account of great weight or for other reasons cannot have its frame insulated, should be surrounded with an insulated platform. This may be of wood, mounted on insulating supports, and so arranged that a man must stand upon it in order to touch any part of the machine.

The leads or branch circuits should be designed to carry a current at least fifty per cent greater than that required by the rated capacity of the motor, to provide for the inevitable overloading of the motor at times, without over-fusing the wires.

The motor and resistance box should be protected by a cut-out or circuit breaker, and controlled by a switch, the switch plainly indicating whether "on" or "off." Where one-fourth horse power or less is used on low-tension circuits a single-pole switch will be accepted. The switch and rheostat should be located within sight of the motor, except in cases where special permission to locate them elsewhere is given, in writing, by the Inspection Department having jurisdiction.

In connection with motors the use of circuit breakers, automatic starting boxes and automatic under-load switches is recommended, wherever it is possible to install them.

Motors should not be run in series, multiple, or multiple-series, except on constant-potential systems, and then only by special permission of the Inspection Department having jurisdiction.

Like generators, they should be covered with a waterproof cover when not in use, and if necessary, should be inclosed in an approved case.

Motors, when combined with ceiling fans, should be hung from insulated hooks, or there should be an insulator interposed between the motor and its support.

Every motor should be provided with a name-plate, giving the maker's name, the capacity in volts and amperes, and the normal speed in revolutions per minute.

One rule at all times to be remembered in starting and stopping motors is, *Switch first, rheostat last,* which means, in starting, close the switch first, and then gradually cut out all resistance as the motor speeds up, and to stop the motor open the switch first and then cut in all the resistance of the rheostat which is in series with the motor armature.

When starting any new motor for the first time, see that the belt is removed from the pulley and the motor started with no load. Never keep the rheostat handle on any of its coils longer than a moment, as they are not designed to regulate the speed of the motor but to prevent too large a flow of current into the armature before the latter has attained its full speed.

Fig. 1 shows a rheostat which is designed to protect automatically the armature of a motor. The contact arm is fitted with a spring which constantly tends to throw the arm on the "off point" and open the circuit, but is prevented from so doing, while the motor is in operation, by the small electro-magnet, shown on the face of the rheostat, which consists of a low-resistance coil connected in series with the field winding of the motor. This magnet holds the contact arm of the rheostat in the position allowing the maximum working current to flow through the armature while it is in operation.

If, for any reason, the current supplied to the motor be momentarily cut off, the speed of the armature generates a counter current which also tends to hold the arm in position as long as there is any motion to the motor armature; but as soon as the armature ceases to revolve, all current ceases to flow through the electro-magnet, thereby releasing the rheostat handle, which flies back to the "off point," as shown in the illustration, and the moter armature is out of danger. Such a device is of great value where inexperienced men have to handle motors, and are unaware that the first thing to be done when a motor stops, for any reason whatever, is to open the circuit, and then cut in all the resistance in the rheostat to prevent too large an in-rush of current when the motor is started up again.

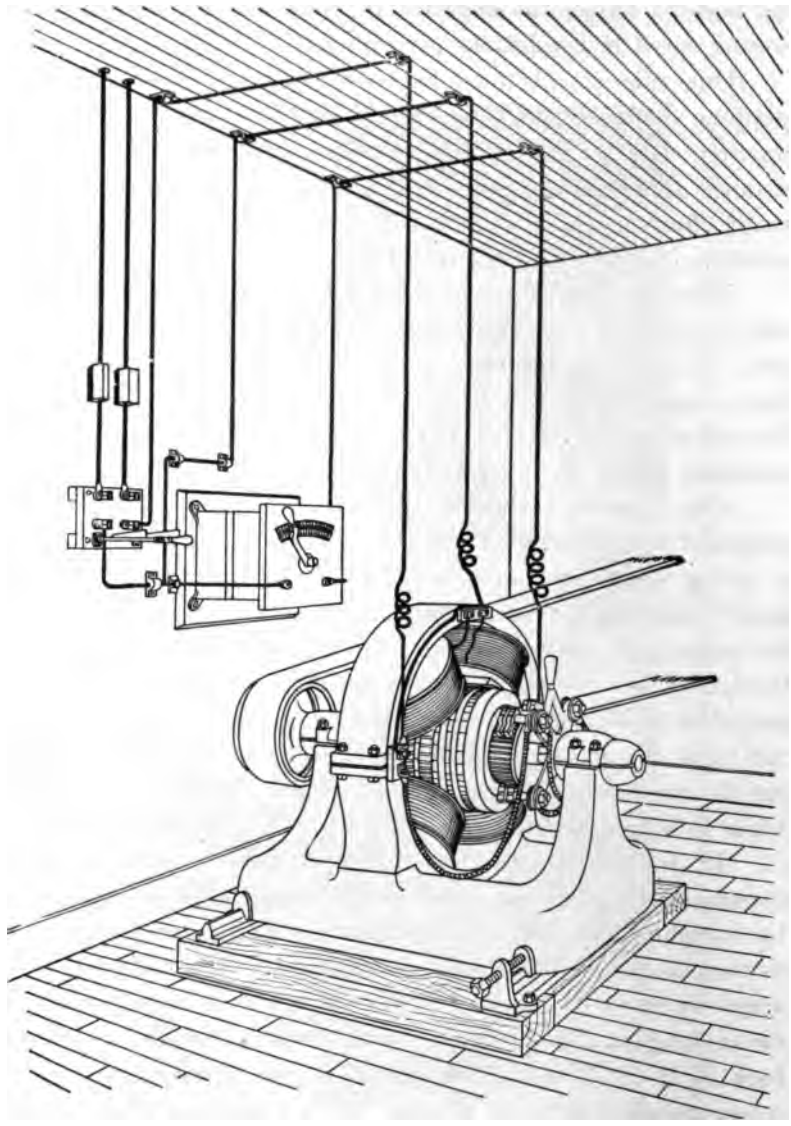


Fig. 1.

An approved installation in every detail; wiring connections for shunt-wound 4-pole motor, using double-pole fuse cut-out instead of circuit breaker.

The Circuit Breaker for under and over loads is also a most valuable protection in such cases.

Motor Wiring Formulæ—(Direct Current). To find the size of wire, in circular mils, required to transmit any power any distance at any required voltage and with any required loss, we have the following formula. Having found the required number of circular mils, it is advisable to add 50 per cent more for safety.

e = potential of motor. d = distance from generator to motor.
v = volts lost in lines. k = efficiency of motor.
10.8 = resistance in ohms of 1 foot of 97 per cent pure copper wire one mil in diameter.

$$\text{c.m.} = \frac{\text{h. p. of motor} \times 746 \times 2d \times 10.8}{e \times v \times k}$$

To find size of wire from c.m., see table, page 37.

AVERAGE MOTOR EFFICIENCY.

1 h. p.	75 per cent
3 h. p.	80 per cent
5 h. p.	80 per cent
10 h. p. and over	90 per cent

For Most Cases—(Small Installations). The table and examples worked out on pages 38, 39 and 40 will give the desired results without the above formulæ.

To find current required by a motor when the horse power, efficiency and voltage are known, use the following formula:

Let C = current to be found. H. P. = horse power of motor.
E = voltage of motor circuit. K = efficiency of motor.

$$C = \frac{H.P. \times 746 \times 100}{E \times K}$$

Or, when possible, use table I.

By adding the volts indicated in table II. to the voltage of the lamp or motor, the result shows the voltage at the dynamo for losses indicated. Thus 10 per cent on 110-volt system is: 12.22 volts added to 110 equal 122.22, showing that the dynamo must generate 122.22 volts for a 10 per cent loss.

TABLE I.

Amperes Per Motor.

H. P.	Per Cent.	Watts	THE TOP ROW INDICATES VOLTS.									
			50	75	110	220	400	500	600	800	1000	1200
¼	75	746	14.9	9.94	6.79	3.38	1.86	1.48	1.24	.93	.746	.62
1½	75	1492	29.8	19.8	13.56	6.78	3.73	2.98	2.48	1.86	1.492	1.24
3	80	2797	55.9	37.2	25.4	12.7	6.99	5.59	4.66	3.49	2.797	2.33
5	80	4662	93.2	62.1	42.3	21.1	11.65	9.32	7.77	5.82	4.662	3.88
7½	90	6217	124.	82.9	56.5	28.2	15.54	12.43	10.36	7.77	6.217	5.18
10	90	8288	165.	110.	75.5	37.6	20.72	16.57	13.81	10.36	8.288	6.90
15	90	12433	248.	165.	113.	56.5	31.08	24.86	20.72	15.53	12.43	10.36
20	90	16578	331.	221.	150.	75.3	41.44	33.15	27.63	20.72	16.57	13.98
25	90	20722	414.	276.	188.	94.1	51.8	41.6	34.5	25.9	20.7	17.2
30	90	24866	497	331.	226.	113.	62.	49.7	41.4	31.	24.8	20.7
40	90	33155	663.	442.	301.	150.	82.8	66.3	55.2	41.4	33.1	27.6
50	90	41444	828.	552.	376.	188.	103.	82.8	69.	51.8	41.4	34.5
60	90	49733	994.	663.	452.	226.	124.	99.4	82.8	62.	49.7	41.4
70	90	58022	1160.	773.	527.	263.	145.	116.	96.7	72.5	58.	48.3
80	90	66311	1326.	884.	602.	301.	165.	132.	110.	82.9	66.3	55.2
90	90	74599	1491.	994.	678.	339.	186.	149.	124.	93.	74.5	62.
100	90	82888	1657.	1105.	753.	376.	207.	165.	138.	103.	82.8	69.
120	90	99457	1989.	1326.	904.	452.	248.	198.	165.	124.	99.	82.8
150	90	124312	2486.	1657.	1131.	565.	310.	248.	207.	155.	124.	103.

TABLE II.

Volts Lost at Different Per Cent Drop.

Drop per cent.	VOLTAGE.											
	52	75	100	110	220	400	500	600	800	1000	1200	2000
¼	.261	.376	.502	.552	1.10	2.01	2.51	3.01	4.02	5.02	6.03	10.05
1	.525	.757	1.01	1.11	2.22	4.04	5.05	6.06	8.08	10.10	12.12	20.2
1½	.2918	1.14	1.52	1.67	3.35	6.09	7.61	9.13	12.1	15.2	18.2	30.4
2	1.06	1.53	2.04	2.24	4.48	8.16	10.2	12.2	16.3	20.4	24.4	40.8
2½	1.33	1.92	2.56	2.82	5.64	10.25	12.8	15.3	20.5	25.6	30.7	51.2
3	1.61	2.31	3.09	3.40	6.80	12.37	15.4	18.5	24.7	30.9	37.1	61.8
4	2.16	3.12	4.16	4.58	9.16	16.66	20.8	24.9	33.3	41.6	49.9	83.3
5	2.73	3.94	5.26	5.78	11.57	21.05	26.3	31.5	42.1	52.6	63.1	105.
6	3.31	4.78	6.38	7.02	14.04	25.53	31.9	38.2	51.	63.8	76.5	127.
7	3.91	5.64	7.52	8.27	16.55	30.10	37.6	45.1	60.2	75.2	90.3	150.
8	4.52	6.52	8.69	9.56	19.13	34.78	43.4	52.1.	69.5	86.9	104.	173.
9	5.14	7.41	9.89	10.87	21.75	39.56	49.4	59.3	79.1	98.9	118.	197.
10	5.77	8.33	11.11	12.22	24.44	44.44	55.5	66.6	88.8	111.	133.	222.
11	6.42	9.26	12.35	13.59	27.19	49.43	61.7	74.1	98.8	123.	148.	247.
12	7.09	10.22	13.63	14.99	29.99	54.54	68.1	81.8	109.	136.	163.	272.
13	7.76	11.10	14.94	16.43	32.87	59.76	74.7	89.6	119.	149.	179.	298.
14	8.46	12.20	16.27	17.90	35.81	65.1	81.3	97.6	130.	162.	195.	325.
15	9.17	13.23	17.64	19.41	38.82	70.5	88.2	105.	141.	176.	211.	352.
20	13.	18.75	25.	27.50	55.	100.	125.	150.	200.	250.	300.	400.
25	17.33	25.	33.33	36.66	73.33	133.	166.	200.	266.	333.	400.	666.

OUTSIDE WIRING AND CONSTRUCTION.

Service Wires (those leading from the outside main wire to the buildings and attached to same) should be "Rubber-Covered."

Line Wires, other than service wires, should have an approved "weatherproof covering."

Bare Wires may be used through uninhabited and isolated territories free from all other wires, as in such places wire cover-

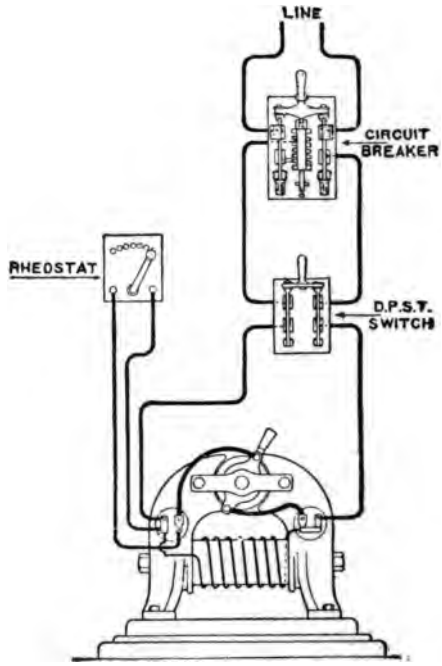


Fig. 2.

An approved installation in every detail; wiring connections for shunt-wound bipolar motor, using circuit breaker instead of double-pole fuse cut-out.

ing would be of little use, as it is not relied on for pole insulation, and is not needed for other purposes, because the permanent insulation of the wires from the ground is assured by the glass or porcelain petticoat insulators to which the wires are secured.

Tie Wires should have an insulation equal to that of the conductors they confine.

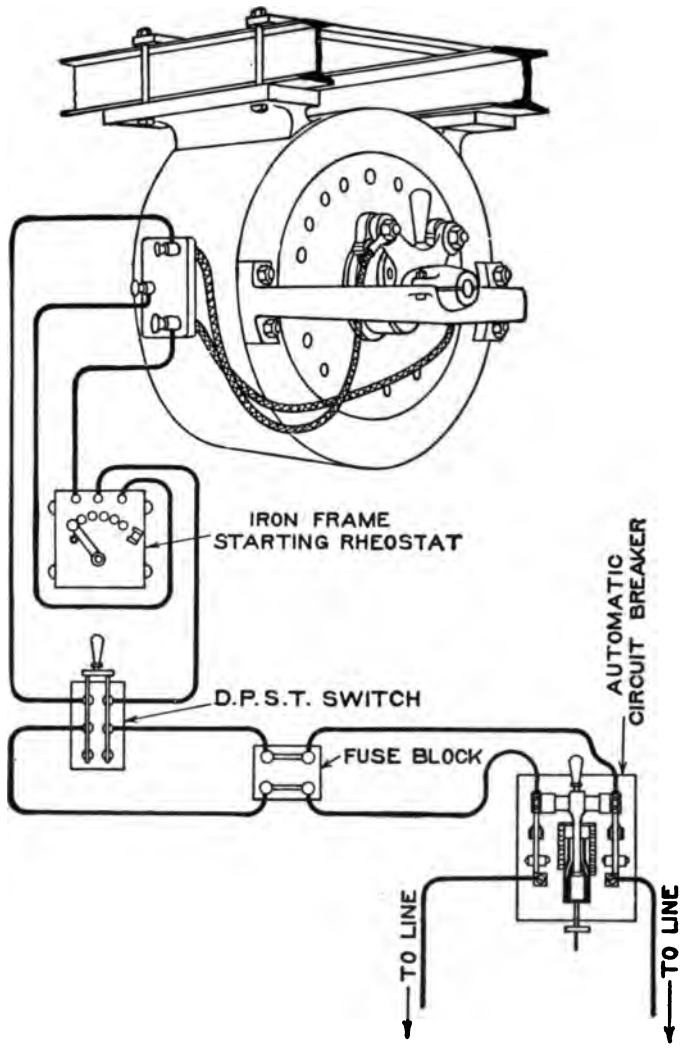
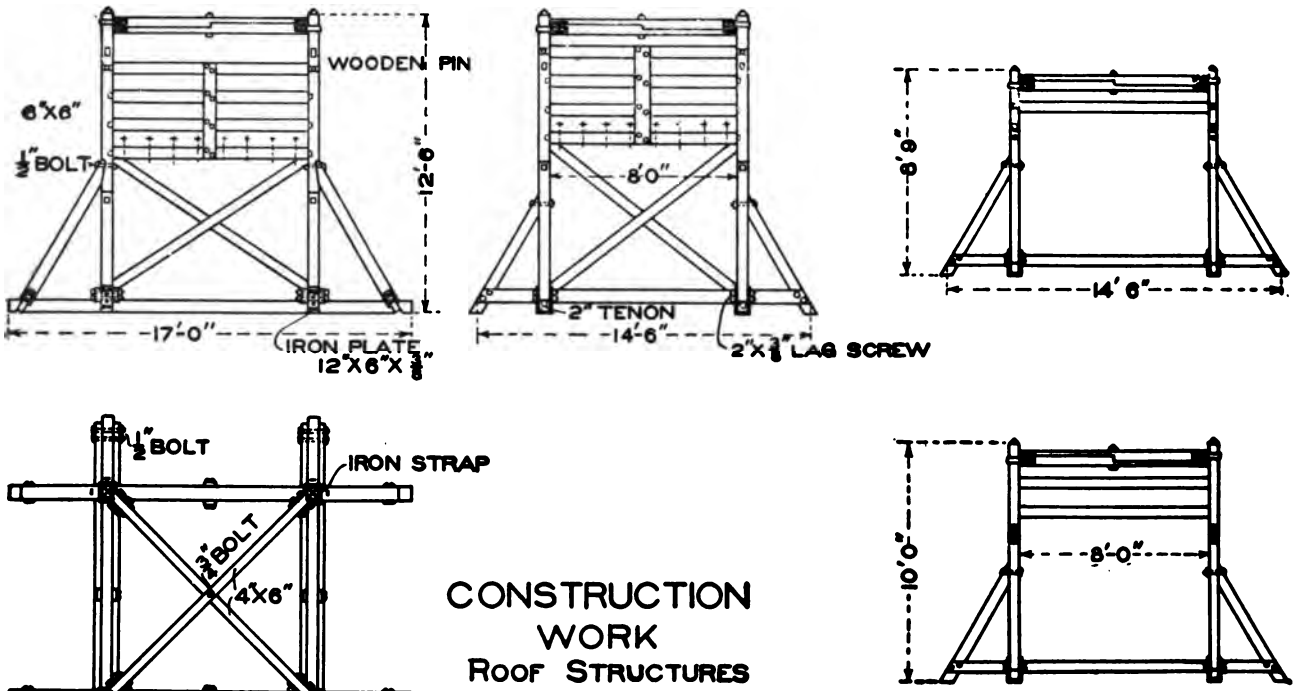


Fig. 3.

An approved installation in every detail, with wiring connections for shunt-wound multipolar slow speed ceiling motor for direct connection to line shaft Using both circuit breaker and double-pole fuse cut-out.



CONSTRUCTION WORK

Roof Structures

Fig. 4.

Space Between Wires for outside work, whether for high or low tension, should be at least one foot, and care should be exercised to prevent any possibility of a cross connection by water. Wires should never come in contact with anything except their insulators.

Roof Structures. If it should become necessary to run wires over a building, the wires should be supported on racks which will raise them seven feet above flat roofs or at least one foot above the ridge of pitched roofs. See Fig. 4.

Guard Arms. Whenever sharp corners are turned, each cross arm should be provided with a dead insulated guard arm to prevent the wires from dropping down and creating trouble, should their insulating support give way.

Petticoat Insulators should be used exclusively for all outside work, and especially on cross arms, racks, roof structures and service blocks. Porcelain knobs, cleats or rubber hooks should never be used for this heavy outside work.

Splicing of two pieces of wire or cable should be done in such manner as to be mechanically and electrically secure without solder. The joints should then be soldered to prevent corrosion and consequent bad contact. All joints thus made should be covered with an insulation equal to that of the conductors.

Tree Wiring. Whenever a line passes through the branches of trees, it should be properly supported by insulators, as shown in Fig. 5, to prevent the chafing of the wire insulation and grounding the circuit.

Service Blocks which are attached to buildings should have at least two coats of waterproof paint to prevent the absorption of moisture.

Entrance Wires. Where the service wires enter a building they should have drip loops outside, and the holes through which the conductors pass should be bushed with non-combustible, non-absorptive insulating tubes slanting upward toward the inside. See Fig. 6.

Telegraph and Telephone wires should never be placed on the same cross-arm with light or power wires, especially when alternating currents are used, as trouble will arise from induc-

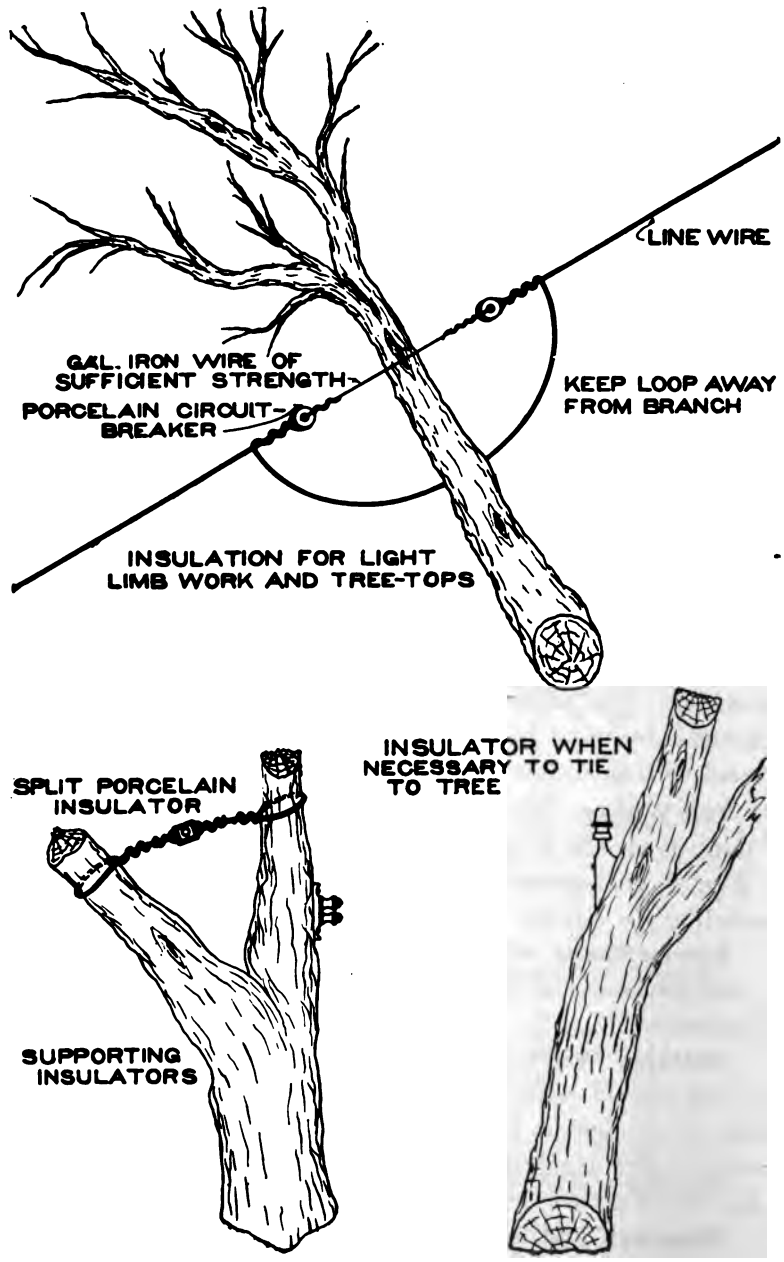

LINE WIRE
GAL. IRON WIRE OF SUFFICIENT STRENGTH
PORCELAIN CIRCUIT-BREAKER
KEEP LOOP AWAY FROM BRANCH
INSULATION FOR LIGHT LIMB WORK AND TREE-TOPS
INSULATOR WHEN NECESSARY TO TIE TO TREE
SPLIT PORCELAIN INSULATOR
SUPPORTING INSULATORS

Fig. 5.

tion, unless expensive special construction, such as the transposing of the lighting circuits, be resorted to at regular intervals. Even under these conditions it is bad practice, as an accidental contact with the lighting or power circuit might result in starting a fire in the building to which the telephone line is connected. If, however, it is necessary to place telegraph or telephone wires on the same poles with lighting or power wires, the distance between the two inside pins of each cross-arm should not be less than twenty-six inches, and the metallic sheaths to cables should be thoroughly and permanently connected to earth.

Transformers should not be placed inside of any buildings except central stations, and should not be attached to the outside walls of buildings, unless separated therefrom by substantial supports.

In cases where it is impossible to exclude the transformer and primary wiring from entering the building, the transformer should be located as near as possible to the point where the primary wires enter the building, and should be placed in a vault or room constructed of or lined with fire-resisting material, and containing nothing but the transformer. In every case the transformer must be insulated from the ground and the room kept well ventilated. It is of course the safest and best practice to place all transformers on poles away from the building that is to be lighted, as illustrated in Fig. 7.

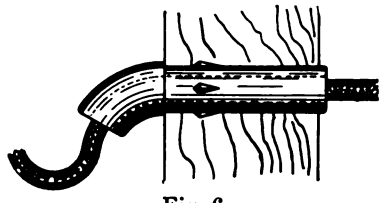


Fig. 6.
Porcelain tube, used where wires enter buildings, showing drip loop in wire.

The Grounding of Low-Potential Circuits is allowed only when such circuits are so arranged that under normal conditions of service there will be no passage of current over the ground wire.

In Direct-Current 3-Wire Systems the neutral wires may be grounded, and when grounded the following rules should be complied with:

1. They should be grounded at the central station on a metal plate buried in coke beneath permanent moisture level, and

also through all available underground water and gas pipe systems.

2. In underground systems the neutral wire should also be grounded at each distributing box through the box.

3. In overhead systems the neutral wire should be grounded every 500 feet.

When grounding the neutral point of transformers or the

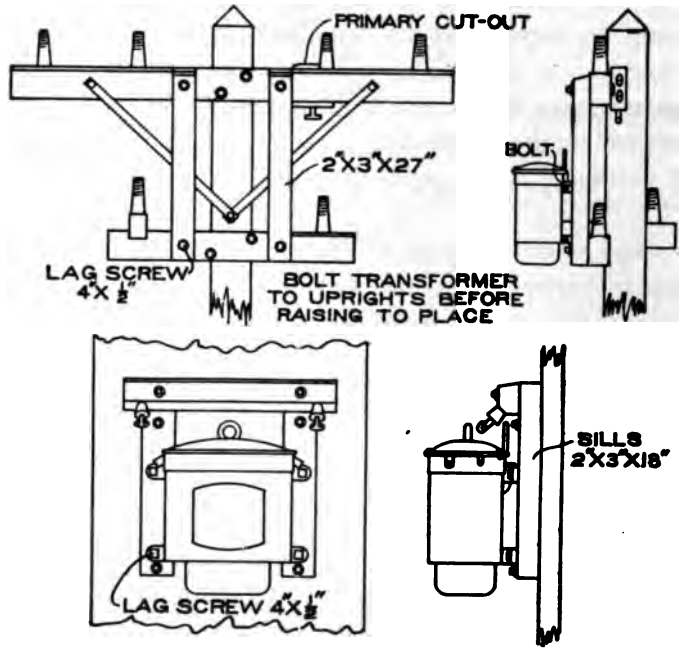


Fig. 7.
Construction work; installing transformers.

neutral wire of distributing systems the following rule should be complied with:

1. Transformers feeding two-wire systems should be grounded at the center of the secondary coils, and when feeding systems with a neutral wire, should have the neutral wire grounded at the transformer, and at least every 500 feet for underground systems.

In making ground connections on low-potential circuits, the ground wire in direct-current 3-wire systems should not at central

stations be smaller than the neutral wire, and not smaller than No. 6 B. & S. elsewhere.

In Alternating-Current Systems the ground wire should never be less than No. 6 B. & S., and should always have equal carrying capacity to the secondary lead of the transformer, or the combined leads where transformers are banked.

These wires should be kept outside of buildings, but may be directly attached to the building or pole, and should be carried in as nearly a straight line as possible, all kinks, coils and sharp bends being avoided.

The ground connection for central stations, transformer sub-stations, and banks of transformers should be made through metal plates buried in coke below permanent moisture level, and connection should also be made to all available underground piping systems, including the lead sheath of underground cables.

For individual transformers and building services the ground connection may be made to water or other piping systems running into the buildings. This connection may be made by carrying the ground wire into the cellar and connecting on the street side of meters, main cocks, etc., but connection should never be made to any lead pipes which form part of gas services.

In connecting ground wires to piping systems, wherever possible, the wires should be soldered into one or more brass plugs and the plugs forcibly screwed into a pipe fitting, or, where the pipe is cast iron, into a hole tapped into the pipe itself. For large stations, where connecting to underground pipes with bell and spigot joints, it is well to connect to several lengths, as the pipe joints may be of rather high resistance. Where such plugs cannot be used, the surface of the pipe may be filed or scraped bright, the wire wound around it, and a strong clamp put over the wire and firmly bolted together.

Where ground plates are used, a No. 16 copper plate, about 3 by 6 feet in size, with about two feet of crushed coke or charcoal, about pea size, both under and over it, would make a ground of sufficient capacity for a moderate-sized station, and would probably answer for the ordinary sub-station or bank of transformers. For a large central station considerable more area might be nece-

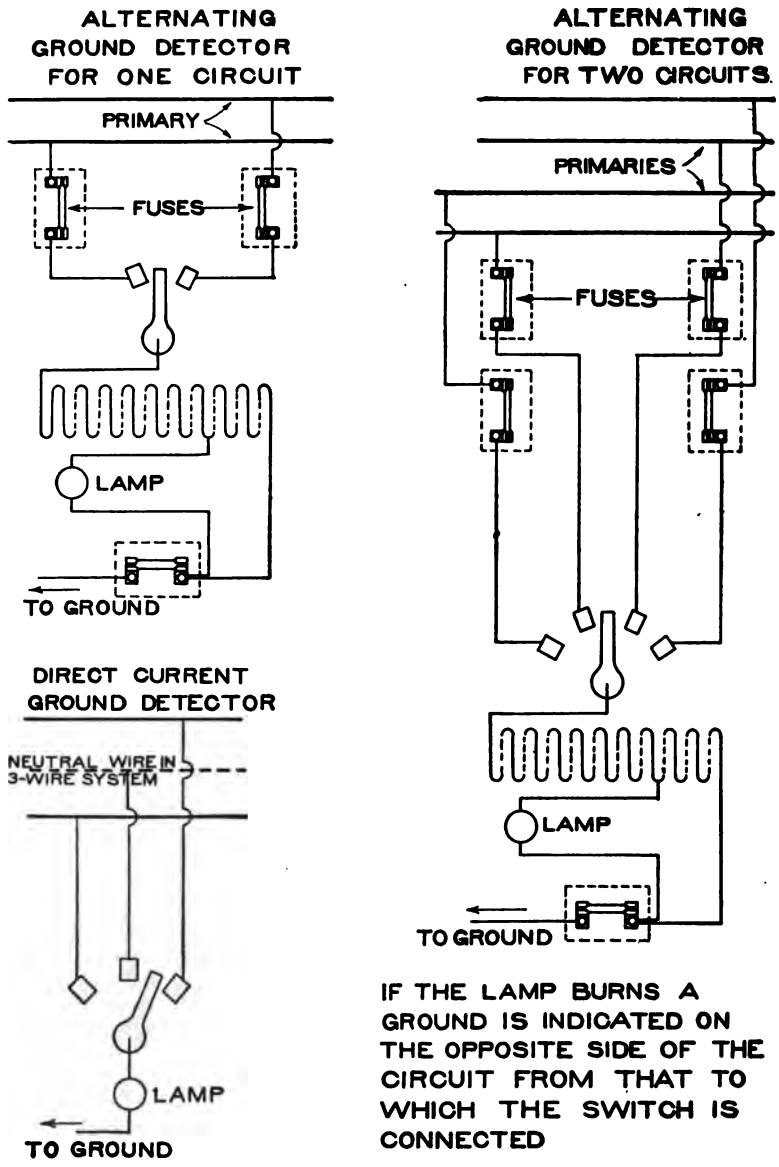


Fig. 8.

Connections of Ground Detectors.

sary, depending upon the underground connections available. The ground wire should be riveted to such a plate in a number of places, and soldered for its whole length. Perhaps even better than a copper plate is a cast iron plate, brass plugs being screwed into the plate to which the wire is soldered. In all cases, the joint between the plate and the ground wire should be thoroughly protected against corrosion, by suitable painting with waterproof paint or some equivalent.

Ground Detectors. Fig. 8 illustrates a few practical methods of detecting grounds on alternating and direct-current circuits which have not been purposely grounded.

In using any one of these methods for detecting grounds, always see that the circuit to ground is left open after testing the outside circuits.

Some central station men are in the habit of leaving the ground circuit closed on one side constantly in order that any ground that might occur on the other side may be instantly noticed. This, however, is bad practice, as it greatly reduces the insulation of the whole system. Test all circuits at least once a day.

It is sometimes necessary to know just what the insulation resistance of a line, or of the wiring in a building, is in ohms. This can be found very readily, and closely enough for all practical purposes, by using a Weston volt meter in the following manner:

Connect with a wire from one side of the circuit to one binding post of the volt meter, and with another piece of wire connect a water pipe to the other binding post of the volt meter. If the needle or pointer shows any deflection we know there is a ground, or leakage, on the opposite side of the circuit to which the volt meter is connected.

The resistance of this ground leak may be found by the following formula:

$R = r\left(\frac{v}{v} - 1\right)$ ohms when R = resistance of ground leak required, r = resistance of volt meter, V = voltage between the positive and negative sides of the line, v = reading in volts, on the instrument, produced by the leakage.

Primary Wiring. Primary wires should be kept at least ten inches apart, and at that distance from conducting material. Primary wires carrying over 3,500 volts should not be brought into or over any building other than the central power station or sub-station.

Wires for Outside Use have in most cases a "weatherproof" insulation, except service wires, which should be "rubber-covered." Any insulating covering for wires exposed to the weather on poles is in a short time rendered useless. The real insulation of the system will be found to be dependent upon the porcelain or glass insulators.

POLES FOR LIGHT AND POWER WIRES.

It is essential to a proper installation that the poles receive due consideration, a fact that is too often overlooked.

In selecting the style of pole necessary for a certain class of work the conditions and circumstances should be considered. Poles may be arranged in three classes, the size of wire which they are to carry respectively being one of the important regulating circumstances.

First Class: Alternating-current plants for lighting small towns. Main line of poles should consist of poles from 30 to 35 feet long, with 6-inch tops. These are strong enough for all the weight that is placed upon them. No pole less than 30 feet with 6-inch top should be placed on a corner for lamps. The height of trees, of course, must be considered in many cases. For the Edison municipal system, where more than one set of wires are used for street lighting, a 6-inch top should be the size of the poles, the length being not less than 30 feet, and greater than this if the streets be hilly and filled with trees.

Second Class: Town lighting by arc lights. All poles should be at least 6-inch tops. The corner poles should be 6½-inch tops; and wherever the cross-arms are placed on a pole at different angles, the pole should be at least a 6½-inch top. A 30-foot pole is sufficiently long for the main line, but it would be advisable to place 35-foot poles on corners.

Third Class: Where heavy wire, such as No. 00, is used for feeder wire, the poles should be at least 7-inch tops. Where mains are run on the same pole line the strain is somewhat lessened, and poles of smaller size will answer all purposes.

Cull Poles. The question as to what is a cull pole is something on which many authorities differ. Of course, if specifications call for a certain sized pole, parties supplying the poles should be compelled to send the sizes called for. All poles that are smaller at the top than the sizes agreed upon, are troubled with dry rot, large knots and bumps, have more than one bend, or have a sweep of over twelve inches, should certainly be classed as cull poles. Specifications for electric light and power work should be, and in many cases are, much more severe than those required by telegraph lines. A cull pole, one of good material, is the best thing for a guy stub, and is frequently used for this purpose. A cedar pole is always preferable to any other, owing to the fact that it is very light compared with other timber, and is strong, durable and very long lived.

Pole Setting. It seems to be the universal opinion of the best construction men that a pole should be set at least five feet in the ground, and six inches additional for every five feet above thirty-five feet. Also additional depths on corners. Wherever there is much moisture in the ground, it is well to paint the butt end of the pole, or smear it with pitch or tar, allowing this to extend about two feet above the level of the ground. This protects the pole from rot at the base. The weakest part of the pole is just where it enters the ground. Never set poles farther than 125 feet apart; 110 feet is good practice.

Pole Holes should be dug large enough so that the butt of the pole can be dropped straight in without any forcing, and when the pole is in position only one shovel should be used to fill in, the earth being thoroughly tamped down with iron tampers at every step until the hole is completely filled with solidly packed earth. Where the ground is too soft for proper tamping, a grouting composed of one part of Portland cement to two parts of sand, mixed with broken stone, may be used to make an artificial foundation.

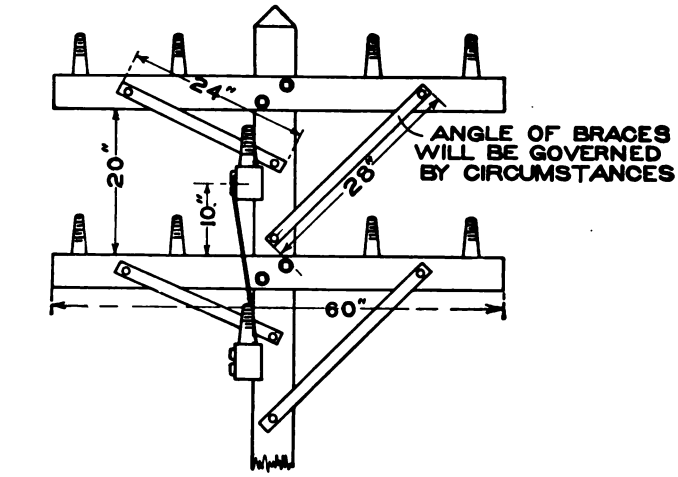


FIG. 1

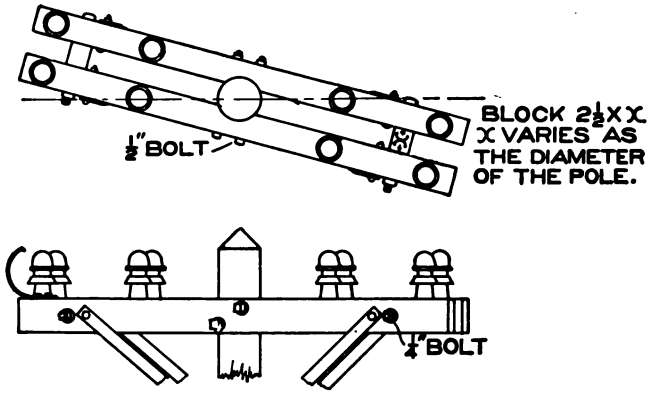


FIG. 2

Fig. 9.

CONSTRUCTION WORK; POSITION OF CROSS-ARMS WHEN TURNING CORNERS.

When running a heavy line wire it is necessary to use two cross-arms fastened as shown above in Fig. 2. If lines are not heavy, only one cross-arm will be necessary. In case lines cross the street diagonally, the arms where the wires leave and those to which they run are both set at an angle. When turning an abrupt corner only one arm is turned. The above cannot be used where feeders tap into double branches. In such a case the method given in Fig. 1 is used.

TABLE III.

Cedar Poles for Electric Light Work.

SIZE.	Average weight, pounds each.	No. of Poles to a Car.	SIZE.	Average weight, pounds each.	No. of Poles to a Car.
25 ft., 5-inch top	200	150	35 ft., 7-inch top	650	90
25 " 5½ " "	225	130	40 " 6 " "	800	80
25 " 6 " "	250	120	40 " 7 " "	900	75
28 " 7 " "	400	80	45 " 6 " "	900	70
30 " 5 " "	300	110	45 " 7 " "	1000	65
30 " 6 " "	350	90	50 " 6 " "	1200	55
30 " 7 " "	420	75	55 " 6 " "	1400	45
35 " 6 " "	550	100			

Painting. When poles are to be painted, a dark olive green color should be chosen, in order that they may be as inconspicuous as possible. One coat of paint should be applied before the pole is set, and one after the pole is set. Tops should be pointed to shed water.

All poles 35 feet long and over must be loaded on two cars.

For chestnut poles add 50 per cent to weights as given in table.

Cross-Arms. The distance from the top of the pole to the cross-arm should be equal to the diameter of pole at the top. All cross-arms should be well painted with one coat of paint before placing, and must be of standard size as shown in the diagrams. Cross-arms of four or more pins should be braced, using one or two braces as occasion demands. Cross-arms on one pole should face those on the next, thereby making the cross-arms on every other pole face in one direction. All pins should have their shanks dipped in paint and should be driven into the cross-arm while the paint is wet. The upper part of the pin should also be painted. Iron pins may be furnished for corners where there is a heavy strain, but are not advised, it being preferable to use the construction as shown in the diagrams. Put double arms on the pole where feeder wires end.

Guard Irons. Guard irons should be placed at all angles in lines, and on break-arms.

Steps. All junction and lamp poles should be stepped so that the distance between steps on the same side of the pole will not be over 36 inches. Poles carrying converters should also be stepped.

TABLE IV.

Pole Line Data.

Gauge Number (B. & S.)	4/0	3/0	2/0	1/0	1	2	3	4	5	6	7	8
Diam. of Bare Wire, in Thousandths...	.460	.40964	.3648	.3249	.2893	.2576	.2294	.2043	.1819	.1620	.1442	.1285
Ohms Res. B. Wire per Mile, 75° Fahr.	.25902	.32667	.41188	.5499	.6910	.8719	1.099	1.400	1.754	2.213	2.812	3.539
Wt. (lbs.) per 1000 feet Insulated Wire	826	611	460	357	300	244	204	168	119	100	84	71
Weight per Mile (approximate) of Insulated Wire	4360	3225	2225	1880	1580	1285	1075	885	625	525	440	373

No. of Poles per Lineal Mile.	Distance Between Poles (feet).	Approximate Weight of Insulated Wire Between Poles.										
20	264.00	218.0	161.3	121.3	94.0	79.0	64.25	53.75	44.25	31.2	26.25	22.	18.65
21	251.40	208.0	153.6	115.5	89.53	75.0	61.2	51.2	42.2	30.0	25.0	20.96	17.8
22	240.10	198.2	146.6	110.3	85.5	71.9	58.5	48.9	40.3	28.41	23.9	20.0	16.96
23	229.56	189.69	140.3	105.5	81.74	68.70	55.88	46.8	38.5	27.17	22.83	19.2	16.22
24	220.00	181.7	134.4	101.0	78.34	65.84	53.54	44.8	36.91	26.05	21.9	18.34	15.55
25	211.20	174.4	129.	97.0	75.20	63.2	51.40	53.0	35.4	25.0	21.0	17.6	14.92
26	203.07	167.7	124.04	93.3	72.40	60.8	49.42	41.34	34.04	24.04	20.19	16.93	14.35
27	195.55	161.5	119.5	89.81	69.63	58.52	47.22	40.00	32.77	23.15	19.45	16.30	13.82
28	188.55	155.7	115.2	86.61	67.50	56.43	45.90	38.39	31.61	22.33	18.76	15.72	13.33
29	182.09	150.34	111.3	83.62	64.82	54.48	44.31	37.07	30.52	21.56	18.11	15.18	12.87
30	176.00	145.34	107.5	80.85	62.67	52.67	42.84	35.84	29.50	20.86	17.50	14.67	12.44
31	170.30	140.65	104.04	78.23	60.65	50.97	41.46	34.68	28.55	20.17	16.94	14.20	12.04
32	165.00	136.25	100.80	75.80	58.75	49.38	40.16	33.60	27.66	19.54	16.41	13.75	11.72
33	160.00	132.13	97.73	73.49	56.97	47.88	38.94	32.58	26.82	18.94	15.91	13.34	11.31
34	155.29	128.24	94.86	71.83	55.30	46.48	37.80	31.62	26.03	18.39	15.45	12.95	10.98
35	150.85	124.58	92.15	69.29	53.72	45.15	36.73	30.72	25.29	17.86	15.00	12.58	10.66
36	146.66	121.12	89.59	67.37	52.23	43.89	35.70	29.87	24.59	17.37	14.59	12.23	10.37
37	142.70	117.84	87.17	65.55	50.82	42.71	34.73	29.06	23.92	16.90	14.19	11.90	10.09
38	138.96	114.74	84.87	63.82	49.48	41.58	33.82	28.29	23.29	16.45	13.82	11.58	9.82
39	135.38	111.80	82.69	62.20	48.21	40.52	32.95	27.57	22.69	16.03	13.47	11.29	9.57
40	132.00	109.00	80.63	60.63	47.00	39.50	32.13	26.88	22.13	15.63	13.13	11.00	9.33
41	128.78	106.35	78.66	59.15	45.86	38.58	31.35	26.22	21.60	15.25	12.81	10.74	9.10
42	125.71	103.81	76.79	57.74	44.77	37.62	30.60	25.60	21.08	14.90	12.50	10.48	8.89
43	122.79	101.49	75.00	56.40	43.73	36.75	29.90	25.00	20.50	14.54	12.21	10.24	8.68
44	120.00	99.10	73.30	55.12	42.73	35.91	29.21	24.44	20.12	14.21	11.94	10.00	8.48
45	117.33	96.89	71.67	53.90	41.80	35.12	28.56	23.90	19.67	13.90	11.67	9.78	8.30
46	114.78	94.79	70.11	52.72	40.88	34.35	27.94	23.37	19.24	13.59	11.42	9.57	8.11
47	112.34	92.77	68.62	51.60	40.00	33.62	27.35	22.90	18.83	13.30	11.18	9.37	7.94
48	110.00	90.84	67.20	50.52	39.17	32.92	26.78	22.40	18.44	13.03	10.94	9.17	7.78
49	107.75	88.99	65.82	49.49	38.36	32.25	26.03	21.94	18.07	12.77	10.72	8.98	7.62
50	105.60	87.20	64.50	48.50	37.60	31.60	25.70	21.50	17.70	12.50	10.50	8.80	7.46
51	103.52	85.50	63.24	47.55	36.97	31.00	25.20	21.09	17.36	12.26	10.30	8.63	7.32
52	101.53	83.85	62.02	46.64	36.16	30.39	24.75	20.68	17.02	12.02	10.10	8.47	7.18
53	99.64	82.27	60.86	45.76	35.48	29.82	24.25	20.29	16.70	11.80	9.92	8.31	7.04
54	97.77	80.75	59.73	44.91	34.82	29.26	23.80	19.91	16.40	11.58	9.73	8.15	6.91
55	96.00	79.28	58.64	44.10	34.19	28.73	23.37	19.55	16.10	11.37	9.55	8.00	6.78

Guys. All poles at angles in the line must be properly guyed, using No. 4 B. & S. galvanized iron wire, or two No. 8 wires twisted. All junction poles should also be guyed. Never attach a guy wire to a pole so that it prevents a cross-arm from being removed.

For alternating work, double petticoat insulators are recommended. Pole brackets, except in connection with the tree insulators, should not be used.

Tape should be secured at either end of a joint by a few turns of twine. When looping for lamps, etc., leave coiled sufficient wire, without waste, to reach lamp or building without joints. In cutting arc or incandescent lamps into an existing circuit, use a piece of "rubber-covered" wire. Feeder wires should be strung on the cross-arms above the mains.

For good distribution, arc lamps should not be placed more than 800 feet apart. The lamps may be brought nearer together if a greater degree of illumination is desired.

Primary Wires on Poles. When running more than one circuit of primaries upon the same line of poles the wires of each circuit should be run parallel and on adjacent pins, as shown below, so as to avoid any fluctuation in the lamps due to induction. The lines lettered A and A are for circuit No. 1, and B and B for circuit No. 2, etc.

.....A
.....A
.....B
.....B

When connecting transformers to 1,000-volt mains a double-pole cut-out is placed in the primary circuit. For 2,000-volt circuits a single-pole cut-out should be placed in each side of the line, thus avoiding any possible short circuit due to an arc being established across the contacts of the double-pole cut-out. This, owing to the greater difference of potential between opposite poles, is liable to occur when the fuses "blow."

INSIDE WIRING.

Approved "Rubber-Covered" Wire should be used exclusively in all interior wiring. Although the Fire Underwriters

allow "Slow Burning" weatherproof wire to be used in dry places when wiring is entirely exposed to view and rigidly supported on porcelain or glass insulators, "Rubber-Covered" wire is always preferable.

The copper conductors, before being rubber covered, should be thoroughly tinned, and the thickness of the rubber covering should conform to the following table:

TABLE V.

Requisite Thickness of Rubber Covering for Wires.

For voltages up to 600:

From No.	18	to No.	16	inclusive,	$\frac{1}{64}$	in.
"	14	to "	8	"	$\frac{3}{64}$	in.
"	7	to "	2	"	$\frac{1}{16}$	in.
"	1	to "	0000	"	$\frac{5}{64}$	in.
"	0000	to "	500000 c. m.	"	$\frac{3}{32}$	in.
"	500000 c. m.	to "	1000000 "	"	$\frac{7}{64}$	in.
Larger than		"	1000000 "	"	$\frac{1}{8}$	in.

For voltages between 600 and 3,500:

From No. 14 to No.	1	inclusive,	$\frac{3}{32}$	in.	
" 0 to "	500000 c. m.	"	$\frac{5}{32}$	in.	} covered by
Larger than	500000 "	"	$\frac{4}{32}$	in.	} braid or tape.

"Slow Burning Weatherproof" Wire should have an insulation consisting of two coatings, the inner one to be fireproof in character and the other to be weatherproof. The inner fireproof coating should comprise at least six-tenths of the total thickness of the wall.

The complete covering should be of a thickness not less than that given in the following table:

TABLE VI.

Requisite Thickness of Slow Burning Weatherproof Insulation.

From No.	14	to No.	8	inclusive,	$\frac{3}{64}$ in.
"	7	to "	2	"	$\frac{1}{16}$ in.
"	2	to "	0000	"	$\frac{5}{64}$ in.
"	0000	to "	500000 c. m.	"	$\frac{3}{32}$ in.
"	500000 c. m.	to "	1000000 "	"	$\frac{7}{64}$ in.
Larger than		"	1000000 "	"	$\frac{1}{8}$ in.

"Weatherproof" Wire, for out-door use, should consist of at least three braids thoroughly impregnated with a dense moisture-repellant which should stand a temperature of 180° Fahrenheit without dripping. The thickness should correspond to that of "Slow Burning Weatherproof" and the outer surface should be thoroughly slicked down.

Carrying Capacity of Wires. Table VII gives the safe carrying capacity of wires from No. 18 B. & S. to cables of 2,000,000 circular mils.

No wires smaller than No. 14 should be used except for fixture wiring and pendants, in which cases as small as No. 18 may be used.

TABLE VII.

Safe Carrying Capacity of Wires.

Gauge No. B. & S. Diameter Mils. Area Circular Mils. No. Amperes Open Work. No. Amperes Concealed Work. Ohms Per 1000 Ft. Lbs. per 1000 Ft. Bare. Lbs. Per 1000 Ft. Insulated. No. and Size of Wires for Cables.

Gauge No. B. & S.	Diameter, Mils.	Area, Circular Mils.	No. Amperes, Open Work.	No. Amperes, Concealed Work.	Ohms per 1000 Ft.	Lbs. per 1000 Ft. Bare.	Lbs. per 1000 Ft. Insulated.	No. and Size of Wires for Cables.
18...	40	1,624	5	3	6.3880	4.92	18	
17...	45	2 048	6	4	5.0660	6.20	21	
16...	51	2,583	8	6	4.0176	7.82	25	
15...	57	3,257	10	8	3.1860	9.86	31	
14...	64	4,106	16	12	2.5266	12.44	38	
13...	72	5,178	19	14	2.0037	15.68	43	
12...	81	6,530	23	17	1.5890	19.77	48	
11...	91	8,234	27	21	1.2602	24.93	64	
10...	102	10,380	32	25	.99948	31.44	80	
9...	114	13,090	39	29	.79242	39.65	97	
8...	128	16,510	46	33	.62849	49.99	116	
7...	144	20,820	56	39	.49845	63.03	118	
6...	162	26.250	65	45	.39528	79.49	166	
5...	182	33,100	77	53	.31346	100.23	196	
4...	204	41,740	92	63	.24858	126.40	228	
3...	229	52,630	110	75	.19714	159.38	265	
2...	258	66,370	131	88	.15633	200.98	296	
1...	289	83,690	156	105	.12398	253.43	329	
0...	325	105,600	185	125	.09827	319.74	421	
00...	365	133,100	220	150	.07797	402.97	528	
000...	410	167,800	262	181	.06134	508.12	643	
0000...	460	211,600	312	218	.04904	640.73	815	
Cables.	630	300,000	405	273	.03355	932.		37-090
"	727.3	400,000	503	332	.02516	1242.		37-1039
"	814.5	500,000	595	390	.02013	1553.		61-0905
"	891.9	600,000	682	440	.01666	1863.		61-0991
"	963.9	700,000	765	488	.01438	2174.		61-1071
"	1030.5	800,000	846	540	.01258	2474.		61-1145
"	1092.6	900,000	924	585	.01118	2795.		61-1214
"	1152.	1,000,000	1000	630	.01006	3106.		61-128
"	1208.7	1 100,000	1075	675	.00915	3416.		61-1343
"	1262.8	1,200,000	1147	715	.00838	3727.		91-1148
"	1314.5	1,300,000	1217	755	.00769	4038.		91-1195
"	1364.	1,400,000	1287	795	.00715	4348.		91-124
"	1413.5	1,500,000	1356	835	.00667	4658.		91-1285
"	1458.6	1,600,000	1423	875	.00625	4968.		91-1326
"	1503.7	1 700,000	1489	910	.00588	5278.		91-1367
"	1547.7	1,800 000	1554	945	.00556	5588.		127-1195
"	1571.9	1,900,000	1618	980	.00527	5898.		127-1223
"	1630.2	2,000,000	1681	1015	.00500	6208.		127-1254

Weight of insulations on cables varies for different kinds of work.

Tie Wires should have an insulation equal to that of the conductors they confine.

Splicing should be done in such manner as to make the wires mechanically and electrically secure without solder; then they should be soldered to insure preservation from corrosion and from consequent heating due to poor contact.

Stranded Wires should have their tips soldered before being fastened under clamps or binding screws. When the stranded wires have a conductivity greater than No. 10 B. & S. copper wire, they should be soldered into lugs. All joints should be soldered in preference to using any kind of splicing device.

Wiring Table. The following examples show the method of using the table on page 40:

1. What size of wire should we use to run 50 16-candle-power lamps of 110 volts, a distance of 150 feet to the center of distribution with the loss of 2 volts?

First multiply the amperes, which will be 25.5 (50 16-c. p. 110-v. lamps take 25.5 amperes, see table on page 57), by the distance, 150 feet, which will equal 3,825 ampere feet. Then refer to the columns headed "Actual Volts Lost"; and as we are to have a loss of two volts only, look down the column headed 2 until you come to the nearest corresponding number to 3,825, and we find that 3,900 is the best number to use. Put your pencil on the number 3,900 and follow that horizontal column to the left until you come to the vertical column headed "Size B. & S.," and you find that a No. 4 B. & S. wire will be the proper size to use in this case.

2. What size of wire should we use to carry current for a motor that requires 30 amperes and 220 volts, and is situated 200 feet from the distributing pole, the "drop" in volts not to exceed 2 per cent?

First multiply 30 amperes by 200 feet, as we did in the first example, and we get 6,000 ampere feet. Now look at the upper left-hand corner of the table and you will see a vertical column headed "Volts." Go down this column until you come to 220, and follow the horizontal column to the right until you come to the figure 1.8, which is the nearest we can come to a 2 per cent loss without a greater loss or "drop." Place your pencil on the figure 1.8 and follow down the vertical column of figures until you come to the nearest corresponding figure to 6,000, which we find to be 6,200. Then with your pencil on this figure follow the horizontal column to the left, and we find that a No. 5 B. & S. wire is a proper size to use for the above conditions.

3. Supposing we have occasion to inspect a piece of wiring, and find a dynamo operating 50 16-c. p. 110-volt lamps at a distance of 150 feet, and our wire gauge shows that wire in use is a No. 12 B. & S., at what loss, or "drop," are these lamps being operated?

First multiply the amperes, which will be 25.5 (50 16-c. p. 110-v. lamps take 25.5 amperes, see table on page 57), by the distance, 150 feet, and we get 3,825 ampere feet. As we find in use a No. 12 B. & S. wire, we look for the vertical column headed "Size B. & S." and follow it down until we come to 12. With our pencil on the figure 12 we travel along the horizontal line to the right until we come to the nearest corresponding number to 3,825, which we find to be 4,575. Then starting at this number we travel up the vertical column and we find a loss of about 15 actual volts, or, practically, a 12 per cent loss, which would greatly reduce the candle-power or brilliancy of the lamps.

Installation of Wires. All wiring should be kept free from contact with gas, water or other metallic piping, or with any other conductors or conducting material which it may cross, by some continuous and firmly fixed non-conductor, creating a separation of at least one inch. In wet places it should be arranged so that an air space will be left between conductors and pipes in crossing, and the former must be run in such a way that they cannot come in contact with the pipe accidentally.

Wires should be run over rather than under pipes upon which moisture is likely to gather, or which by leaking might cause trouble on a circuit. No smaller size than No. 14 B. & S. gauge should ever be used for any lighting or power work, not that it may not be electrically large enough, but on account of its mechanical weakness and liability to be stretched or broken in the ordinary course of usage. Smaller wire may be used for fixture work, if provided with approved rubber insulation.

Wires should never be laid in or come in contact with plaster, cement, or any finish, and should never be fastened by staples, even temporarily, but always supported on porcelain cleats which will separate the wires at least one-half inch from the surface wired over and keep the wires not less than two and one-half

TABLE VIII.

Wiring for Light and Power Circuits.

To find size of wire, multiply current in amperes by single distance and refer to the nearest corresponding number under column of Actual Volts **Lost.**

Volts.	Percentage of Loss.																
2000	1.7	1.5	1.4	1.2	1.1	1.0	0.75	0.5	0.45	0.4	0.35	0.3	0.25	0.2	0.15	0.1	0.05
1000	3.4	2.9	2.7	2.4	2.2	2.0	1.5	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
500	6.5	5.7	5.2	4.8	4.3	3.9	2.9	2.0	1.8	1.6	1.4	1.2	1.0	0.8	0.6	0.4	0.2
220	13.7	12.0	11.0	10.3	9.3	8.3	6.5	4.4	3.9	3.5	3.1	2.7	2.2	1.8	1.4	0.9	0.45
110	——	——	20.0	18.5	17.0	15.4	12.0	8.4	7.6	6.8	6.0	5.2	4.4	3.5	2.7	1.8	0.9
52	——	——	——	——	——	——	22.4	16.1	14.7	13.3	11.8	10.3	8.8	7.1	5.5	3.7	1.9

		Actual Volts Lost.																
*Carrying Capacity, Amperes	Size B. & S.	35	30	27.5	25	22.5	20	15	10	9	8	7	6	5	4	3	2	1
300	0000	345800	296400	271700	247000	222300	197600	148200	98800	88920	79040	69160	59280	49400	39520	29640	19760	9880
245	000	274400	235200	215600	196000	176400	156800	117600	78400	70560	62720	54880	47040	39200	31360	23520	15680	7840
215	00	217525	186450	170912	155375	139837	124300	93225	62150	55935	49720	43505	37290	31075	24860	18645	12430	6215
190	0	172550	147900	135575	123250	110925	98600	73950	49300	44370	39440	34510	29580	24650	19720	14790	9860	4930
160	1	136850	117300	107525	97750	87975	78200	58650	39100	35190	31280	27370	23460	19550	15640	11730	7820	3910
135	2	108500	93000	85250	77500	69750	62000	46500	31000	27900	24800	21700	18600	15500	12400	9300	6200	3100
115	3	86100	73800	67650	61500	55350	49200	36900	24600	22140	19680	17220	14760	12300	9840	7380	4920	2460
100	4	68250	58500	53625	48750	43875	39000	29250	19500	17550	15600	13650	11700	9750	7800	5850	3900	1950
90	5	54250	46500	42625	38750	34875	31000	23250	15500	13950	12400	10850	9300	7750	6200	4650	3100	1550
80	6	43050	36900	33825	30750	27675	24600	18450	12300	11070	9840	8610	7380	6150	4920	3690	2460	1230
60	8	26985	23130	21202	19275	17347	15420	11565	7710	6939	6168	5397	4626	3855	3084	2313	1542	771
40	10	16975	14550	13337	12125	10912	9700	7275	4850	4365	3880	3395	2910	2425	1940	1455	970	485
30	12	10675	9150	8388	7625	6862	6100	4575	3050	2745	2440	2135	1830	1525	1220	915	610	305
22	14	6720	5760	5280	4800	4320	3840	2880	1920	1728	1536	1344	1152	960	768	576	384	192
15	16	4235	3630	3328	3025	2723	2420	1815	1210	1089	968	847	726	605	484	363	242	121

*Note. In case a larger loss than any given in the table is required, proceed as follows: Divide the ampere feet by 10, and then refer to column Actual Volts Lost divided by 10, from which we find the size wire as before.

inches apart. Three-wire cleats may be used when the neutral wire is run in the center and at least two and one-half inches separate the two outside or + and — wires. This style of wiring is intended for low-voltage systems (300 volts or less); and when it is all open work, rubber-covered wire is not necessary, as "weatherproof" wire may be used. Weatherproof wire should not be used in moulding. Wires should not be fished between floors, walls or partitions, or in concealed places, for any great distance, and only in places where the inspector can satisfy himself that the rules have been complied with, as this style of work is always more or less uncertain.

Twin wires should never be used, except in conduits or when flexible conductors are necessary; they are always unsafe for light or power circuits on account of the short distance between them.

All wiring should be protected on side walls from mechanical injury. This may be done by putting a substantial boxing about the wires, allowing an air space of one inch around the conductors, closed at the top (the wire passing through bushed holes) and extending about five feet above the floor. Sections of iron-armored conduit may be used, and in most cases are preferable, as they take up but little room and are very rigid.

If, however, iron pipes are used with alternating currents, the two or more wires of a circuit should always be placed in the same conduit. If plain iron pipe be used the insulation of that portion of each wire within the pipe should be reinforced by a tough conduit tubing projecting beyond the iron tubing at both ends about two inches.

When crossing floor timbers in cellars or in rooms where they might be exposed to injury, wires should be attached, by their insulating supports, to the under side of wooden strips not less than one-half inch in thickness and not less than three inches wide.

GENERAL FORMULÆ FOR LIGHT AND POWER WIRING.

$c.\ m.$=circular mils.

d = length of wire, in feet, on one side of circuit.

n = number of lamps in multiple.

TABLE IX.

Dimensions and Resistances of Copper Wire.

Gauge. No.	Diam. Mils.	Area, Circ. Mils. B. and S. Gauge.	BARE WIRE. Lbs. per 1000 ft.	BARE WIRE. Lbs. per. Mile.	BARE WIRE. Ft. per Pound.	WEATHERPROOF WIRE. Lbs. per 1000 ft.	WEATHERPROOF WIRE. Lbs. per Mile.	WEATHERPROOF WIRE. Ft. per Pound.	*Safe Carrying Capacity, Cur. in Amp.	Ohms per 1000 ft.	Ohms per Mile.	Feet per Ohm.	Area C. M. B. W. G.
0000	460.	211600.	640.73	3383.04	1.56	800	4224.	1.25	312	.04904	.25891	20392.9	206100
000	410.	167800.	508.12	2682.85	1.97	666	3516.	1.50	262	.06184	.32649	16172.1	180600
00	365.	133100.	402.97	2127.66	2.48	500	2640.	2.00	220	.07797	.41168	12825.4	144400
0	325.	105600.	319.74	1688.20	3.13	363	1917.	2.75	185	.09827	.51885	10176.4	115600
1	289.	83690.	253.43	1338.10	3.95	313	1653.	3.20	156	.12398	.65460	8066.0	90000
2	258.	66370.	200.98	1061.17	4.98	250	1320.	4.00	131	.15633	.82543	6396.7	80060
3	229.	52630.	159.38	841.50	6.28	200	1056.	5.00	110	.19714	1.04090	5072.5	67080
4	204.	41740.	126.40	667.38	7.91	144	760.	6.9	92	.24858	1.31248	4022.9	56640
5	182.	33100.	100.23	529.23	9.98	125	660.	8.0	77	.31346	1.65507	3190.2	48400
6	162.	26250.	79.49	419.69	12.58	105	554.	9.5	65	.39528	2.08706	2529.9	41210
7	144.	20820.	63.03	332.82	15.86	87	364.	11.5		.49845	2.63184	2006.2	32400
8	128.	16510.	49.99	263.96	20.00	69	301.	14.5	46	.62849	3.31843	1591.1	27230
9	114.	13090.	39.65	209.35	25.22					.79242	4.18400	1262.0	21900
10	102.	10380.	31.44	165.98	31.81	50	264.	20.0	32	.99948	5.27726	1000.5	17960
11	91.	8234.	24.9	131.65	40.11					1.2602	5 65357	793.56	14400
12	81.	6530.	19.77	104.40	50.58	31	164.	32.0	23	1.5890	8.39001	629.32	11810
13	72.	5178.	15.68	82.792	63.78					2.0037	10.5798	499.06	9025
14	64.	4106.	12.44	65.658	80.42	22	116.	45.0	16	2.5266	13.3405	395.79	6889
15	57.	3257.	9.86	52.069	101.40					3.1860	16.8223	313.87	5184
16	51.	2583.	7.82	41.292	127.87	14	74.	70.0	8	4.0176	21.2130	248.90	4225
17	45.	2048.	6.20	32.746	161.24					5.0660	26.7485	197.39	3364
18	40.	1624.	4.92	25.970	203.31	11	58.	90.0	5	6.3880	33.7285	156.54	2400
19	36.	1288.	3.90	20.594	256.39					8.0555	42.5329	124.14	1764
20	32.	1021.	3.09	16.331	323.32					10.1584	53.6362	98.44	1230

*Safe carrying capacity of exposed wire. Carrying capacity of wire enclosed in moulding is about 40 per cent less. See table on page 37 fifth column.

Approximate weight of weatherproof line wire is 10% less than the weight of underwriters' wire as given above.

served in driving nails into moulding, to avoid puncturing the insulation and possibly grounding the circuit in a way that not only might be difficult to locate, but might cause a concealed fire back of the plastering or wood work to which the moulding is attached.

Moulding should be of hard wood and made of two pieces, a backing and capping, so constructed as to thoroughly encase the wire. It should provide a one-half inch tongue between the conductors and a solid backing, which under the grooves should be not less than three-eighths of an inch in thickness and able to give suitable protection from abrasion.

Concealed Wiring or that which is to be run between walls and floors and their joists, should always be done with approved rubber-covered wire, and should be rigidly supported on porcelain or glass insulators which will separate the wires at least

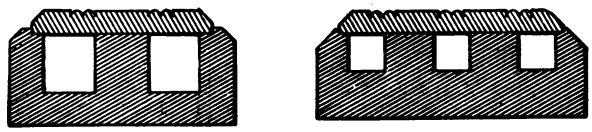


Fig. 10.

Samples of approved moulding when filled and covered with at least two coats of waterproof paint.

one inch from the surface wired over. The wires should be kept at least ten inches apart, and where it is possible should be run singly on separate timbers or joists. The insulators should be placed not farther than four feet apart in any case, and where there is any liability of the wires coming in contact with anything else, due to a possible sagging, the supports should be placed much closer together. In some cases where it is impossible to rigidly support the wiring on porcelain or glass insulators in concealed places, the wires, if not exposed to moisture, may be fished on the loop system if encased throughout in approved continuous flexible tubing or conduit. Fishing under floors or between walls is done by boring holes at suitable distances apart and pushing a flat spring wire from one hole toward the other and catching it with a wire hook. The flexible conduit and wires may then be pulled into place.

This class of wiring should never be concealed or encased except when requested by the Electrical Inspector, and should always be rigidly supported on porcelain or glass insulators which will separate the wiring at least one inch from the surface wired over, and which must be kept at least four inches from each other on all voltages up to 750, and eight inches apart when the voltages exceed 750. No wires carrying a voltage of over 3,500 should be carried into or over any buildings except central stations and sub-stations. All arc light wiring should be protected on side walls and when crossing floor timbers where wires are liable to injury. In mill-construction buildings, arc wires of No. 8 and larger, where not liable to be disturbed, may be separated six inches for voltages up to 750, and ten inches for voltages above 750; may run from timber to timber, not breaking round; and may be supported at each timber only. In running along beams or walls and ceilings they should be supported at intervals not exceeding four and one-half feet.

SPECIAL WIRING.

Special wiring for damp places such as breweries, packing houses, stables, dye houses, paper or pulp mills, or buildings especially liable to moisture or acid or other fumes likely to injure the wires or their insulation, should be done with approved rubber-covered wire, and rigidly supported on porcelain or glass insulators which separate the wires at least one inch from the surface wired over, and which must be kept apart at least two and one-half inches. The wire in such damp places should contain no splices, as it is almost impossible to tape a splice that will prevent acid fumes from getting at the copper surface.

Moulding Work should always be done with approved rubber covered wire to prevent leakage should the moulding become damp.

This class of work should never be done in concealed or damp places, for fear that water may soak into the wood and cause leakage of current between the wires, burning the wood and starting a fire. The action of the current in a case like this is to convert the wood very gradually into charcoal, then dry the water out and ignite the charcoal thus formed. Great care should be ob-

Although this fished work may be passed when the surrounding conditions are, at the time of inspection, perfectly satisfactory, it should be avoided, as trouble will arise in this class of work sooner than in any other, when all conditions are equal.

Insulated Metal Conduits — (Specifications). The metal covering or pipe should be of sufficient thickness to resist penetration by nails, etc., or the same thickness as ordinary gas pipe of the same size.

It should not be seriously affected externally by burning out a wire inside the tube when the iron pipe is connected to one side of the circuit.

The insulating lining should be firmly attached to the pipe, and should not crack or break when a length of conduit is uniformly bent at a temperature of 212 degrees Fahrenheit, to an angle of 90 degrees, with a curve having a radius of 15 inches, for pipes of 1 inch or less, or a radius of fifteen times the diameter of the pipe for larger sizes.

The insulating lining should not soften injuriously at a temperature below 212 degrees Fahrenheit, and should leave water in which it has been boiled, practically neutral.

The insulating lining should be at least one-thirty-second of an inch in thickness; and the materials of which it is composed should be of such a nature as will not have a deteriorating effect on the insulation of the conductor, and be sufficiently tough and tenacious to withstand the abrasion test of drawing in and out of some long lengths of conductors.

The insulating lining should not be mechanically weak after three days' submersion in water, and, when removed from the pipe entire, should absorb more than ten per cent of its weight of water during 100 hours of submersion.

All elbows should be made for the purpose, and not bent from lengths of pipe. The radius of the curve of the inner edge of any elbow should not be less than three and one-half inches.

There should not be more than the equivalent of four quarter bends from outlet to outlet, the bends at outlets not being counted.

Each length of conduit, whether insulated or uninsulated, should have the maker's name or initials stamped in the metal or

attached to it in some satisfactory manner, so that it may be readily seen, thus rendering it possible to place the responsibility for pieces not up to standard.

Uninsulated Metal Conduits or plain iron or steel pipes may be used instead of the insulated metal conduits, if made equally as strong and thick as the ordinary form of gas pipe of the same size, provided their interior surfaces are smooth and free from burrs. To prevent oxidation, the pipe should be galvanized, or the inner surfaces coated or enameled with some substance which will not soften so as to become sticky and prevent the wire from being withdrawn from the pipe. Elbows must be made for the purpose, and not bent from lengths of pipe. The radius of curves and number of bends from outlet to outlet should be the same as given under Insulated Metal Conduits. This bare iron or steel pipe should never contain any but a special extra insulated wire as hereinafter described:

Conduit Wire for Insulated Metal Conduits, whether single or twin conductors, should be standard rubber-covered wire as described on page 35; and where concentric wire is used in insulated metal conduits, it should have a braided covering between the outer conductor and the insulation of the inner conductor, and in addition should comply with and be able to withstand the test of standard rubber-covered wire.

Conduit Wire for Uninsulated Metal Conduits should not only have a standard rubber insulation as required for Insulated Metal Conduits, but in addition should have a second outer fibrous covering at least one-thirty-second inch in thickness, and sufficiently tenacious to withstand the abrasion of being hauled through the metal conduit. When concentric conductors are to be used in uninsulated metal conduits, they not only should comply with the requirements when used in insulated metal conduits, but, in addition, should have a second outer fibrous covering at least one-thirty-second of an inch in thickness and sufficiently tenacious to withstand the abrasion of being hauled through the metal conduit.

Interior Conduit Installation. All conduits should be continuous from one junction box to another or to fixtures, and the

conduit tube should properly enter all fittings, otherwise the conductors are not perfectly protected, and water is much more liable to gain an entrance into the conduit. No conduit with an inside diameter of less than five-eighths inch should be used.

The entire conduit system for a building should be completely installed before a single wire is drawn in; and all ends of conduits should extend at least one-half inch beyond the finished surface of walls or ceilings, except that, if the end is threaded and a coupling screwed on, the conduit may be left flush with the surface, and the coupling may be removed when work on the building is completed.

After all conductors have been drawn or pushed in, all outlets should be plugged up with special wood or fibrous plugs made in parts to fit around the wire, and the outlet then sealed with a good compound to keep out all moisture. All joints should be made air-tight and moisture-proof.

The metal of every conduit system should be effectually and permanently grounded. The conduit is likely to be more or less grounded, and a positive ground is necessary for the same reason that a positive ground is required for generator frames when it is impossible to insulate them perfectly.

Conduit Wiring. The reason why standard rubber covered wire, and not weatherproof, should be used in conduits, is that the best possible insulation is desirable for this class of work, as the insulating lining of the conduit may be defective in places, and there is a possibility of dampness getting into the conduit.

No wires should be drawn in until all mechanical work on the building is done.

Wires of different circuits should not be drawn in the same conduit.

For alternating systems, the two or more wires of a circuit should be drawn in the same conduit, in order to avoid trouble from inductive losses, which, under certain conditions, would cause a heating of the iron conduit to a dangerous degree. This trouble from induction becomes very much less if the wires are in the same conduit; less still, if the wires are twisted together; and disappears almost entirely if concentric wire is used.

Even in direct-current work it is advisable to place the two wires of a circuit in the same conduit, as in so doing the direct current may be changed for the alternating current without the necessity of rewiring, which would be necessary if only a single wire were placed in a conduit.

Fixtures, when supported from the gas piping of a building, should be insulated from the gas-pipe system by means of approved insulating joints placed as close as possible to the ceiling, and the wires near the gas pipe above the insulating joint should be protected from possible contact by the use of porcelain tubes.

All burrs or fins should be removed from the fixtures before the wires are drawn in. The tendency to condensation within the pipes should be guarded against by sealing the upper end of the fixture.

In combination fixtures, where the wiring is concealed between the inside pipe and outer casing, the space between pipe and casing should be at least a quarter of an inch to allow plenty of room for the insulation of the wires without jamming.

Fixtures should be tested for "contacts" between conductors and fixtures, for "short circuits" and for ground connections, before being connected to the supply conductors.

Ceiling blocks of fixtures should be made of insulating material; if not, the wires in passing through the plate should be surrounded by porcelain tubes.

Rosettes. These fittings should not be located where inflamable flyings or dust will accumulate on them. Bases should be high enough to keep the wires and terminals at least one-half inch from the surface to which the rosette is attached.

Terminals with a turned up lug to hold the wire or cord should be used, and in no case must the wire be cut or injured. Fused rosettes are not advised for use where cords can be properly protected by line cut-outs. If fused rosettes are used, the next fuses back should not be over 25 amperes capacity.

Fixture Wiring should be done with fixture wire, which has a solid insulation with a slow-burning, tough, outer covering, the whole at least one-thirty-second of an inch in thickness, and having an insulation resistance between conductors, and between

either conductor and the ground, of at least one megohm per mile, after one week's submersion in water at 70 degrees Fahrenheit, and after three minutes' electrification with 550 volts.

Although No. 18 (B. & S. gauge) is allowable in fixture work, it is never advisable to use smaller than No. 16, for mechanical reasons. Supply conductors, and especially the splices to fixture wires, should be kept clear of the grounded part of gas pipes, and where shells are used the latter should have area enough to prevent pressing the wires against the gas pipe when finally in place. Where fixtures are wired on the outside, it is advisable to use cord for attaching the wires to the fixture, and not short bits of wire, as the latter might produce a short circuit or ground.

Flexible Cord should be made of stranded copper conductors; no single strand should be larger than No. 26 or smaller than No. 30 (B. & S. gauge), and each conductor should be covered by an approved insulation and be protected from mechanical injury by a tough, braided, outer covering. When used for pendant lamps it should hang freely in air and be so placed that there is no chance of its coming in contact with anything excepting the lamp socket to which it is attached and the rosette from which it hangs. Each stranded conductor should have a carrying capacity equivalent to not less than a No. 18 (B. & S. gauge) wire. The covering of the stranded wires for flexible cord should first have a tight, close wind of fine cotton, which is intended to prevent any broken strand from piercing the insulation and causing a short circuit or ground. Secondly, it should have a solid waterproof insulation at least one-thirty-second of an inch thick, and should show an insulation resistance of 50 megohms per mile throughout two weeks' submersion in water at 70 degrees Fahrenheit. The outer protecting braiding should be so put on and sealed in place that when cut it will not fray out.

Flexible cord should not be used as a support for clusters, as it is not strong enough, and it should never be used for anything other than pendants, wiring of fixtures and portable lamps, portable motors, or small, light electrical apparatus.

Flexible cord should never be used in show windows, as a

defective piece might cause a short circuit and set fire to flimsy material or decorations. Many fires have been caused by the use of flexible cord in show windows, where handkerchiefs, decorations, etc., have been pinned to the cord. When the current is "turned on" short circuits are caused by the pins, and a fire is the result.

Insulating bushings should be used where cords enter lamp sockets and desk stand lamps.

Flexible cord should be so suspended that the entire weight of the socket, lamp and shade will be borne by knots under the bushing in the socket, and above the point where the cord comes through the ceiling block or rosette, in order that the strain may be taken from the joints and binding screws. It is good practice always to solder the ends of flexible cords which are going under binding screws, as it holds the strands together and prevents the pressure of the screws from forcing the strands from under them and against the shell of the socket, causing a grounded shell or short circuit.

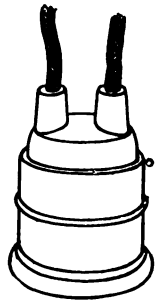


Fig. 11.
Waterproof keyless socket, to be used in dye houses or damp places.

Where it becomes necessary to solder a great number of ends, as may be required when wiring a factory, use a small pot of melted solder and dip the ends of the wire, which have all been previously cut to the proper length.

Standard Lamp Sockets should be plainly marked 50 candle-power, 250 volts, and with either the manufacturer's name or registered trade mark. The inside of the shell of the socket should have an insulating lining which should absolutely prevent the shell from becoming part of the circuit, even though a wire or strand inside the socket should become loose or come out from under a binding screw. This insulating lining should be at least one-thirty-second of an inch thick and of a tough and tenacious material.

Special Lamp Sockets. In rooms where inflammable gases may exist, both the socket and lamp should be enclosed in a vapor-tight globe, supported on a pipe-hanger, and wired with "Rubber-

Covered" wire soldered directly to the circuit. No fuses or switches of any sort should be used in such cases, as the slightest arc might produce dangerous explosions or fires. See Fig. 11.

In damp or wet places, such as dye houses, breweries, etc., a waterproof socket such as shown on page 51 should be used. Waterproof sockets should be hung by separate stranded rubber-covered wires, not smaller than No. 14 (B. & S.). These wires should be soldered direct to the circuit wires, but supported independently of them. All sockets for the above conditions should be keyless.

Stranded Wires in every case should be soldered together before being clamped under binding screws, and when they have a conductivity greater than No. 10 (B. & S.) copper wire they should be soldered into lugs. Stranded wires if not thus stiffened before being clamped under binding posts, are liable to be pressed out or easily worked loose, making a poor contact, which causes heating, a possibility of arcing or a complete burn out, or fusing of the wire at this point.

Bushings. All wires should be protected when passing through walls, partitions or floors, by non-combustible, non-absorptive insulating tubes, such as glass or porcelain. Each bushing should be long enough to go clear through and allow a projection of at least a quarter of an inch on both ends. Bushings should be long enough to bush the entire length of the hole in one continuous piece; or else the hole should first be bushed by a continuous waterproof tube, which may be a conductor, such as iron pipe, and the tube then should have a non-conducting bushing pushed in at each end so as to keep the wire absolutely out of contact with the conducting pipe.

Automatic Cut-outs such as circuit breakers and fuses should be placed on all service wires as near as possible to the point where they enter the building, on the inside of the walls, and arranged to cut off the entire current from the building.

The cut-out or circuit breaker should always be the first thing that the service wires are connected to after entering the building; the switch next, and then the other fixtures or devices in their order. This arrangement is made so that the cut-out or

circuit breaker will protect all wiring in the building, and the opening of the switch will disconnect all the wiring.

These automatic cut-outs should not, however, be placed in the immediate vicinity of easily ignitible stuff, nor where exposed to inflammable gases or dust, or to flyings of combustible material, as the arcing produced whenever they break the circuit might cause a fire or explosion. When they are exposed to dampness they should be inclosed in a waterproof box or mounted on porcelain knobs. All cut-outs and circuit breakers should be supported on bases of non-combustible, non-absorptive insulating material. Cut-outs should be provided with covers when not arranged in approved cabinets, so as to obviate any danger of the melted fuse metal coming in contact with any ignitible substance.

Cut-outs should operate successfully under the most severe conditions they are liable to meet with in practice, on short circuits, with fuses rated at 50 per cent above, and with a voltage 25 per cent above, the current and voltage for which they are designed. Circuit breakers should also be designed to operate successfully under the severe conditions liable to be met with in practice, or at 50 per cent above the current and with a voltage of 25 per cent above that for which they are designed. All cut-outs and circuit breakers should be plainly marked, and where it will always be visible, with the name of the maker as well as the current and voltage for which the device is designed.

Cut-outs or circuit breakers should be placed at every point where a change is made in the size of wire, unless such a device in the larger wire will protect the smaller. They should never be placed in canopies or shells of fixtures, but should be so placed that no set of incandescent lamps, whether grouped on one fixture or several fixtures or pendants, requiring a current of more than six amperes, should be dependent upon one cut-out. Special permission may be given in writing by the Inspection Department having jurisdiction, in case extra large or special chandeliers are to be used. Fused rosettes, when used with flexible cord pendants, are considered as equal to a cut-out. Fuses for cut-outs should not have a capacity to exceed the carrying capacity of the wire; and where circuit breakers are used they should not be set more

than 30 per cent above the allowable carrying capacity of the wire, unless a fusible cut-out is also installed in the circuit.

Circuit breakers open at exactly the current they are set for, and instantly; therefore it is necessary to get them considerably above the ordinary amount of current required, to keep them from constantly opening on slight fluctuations. When this is the case a double-pole fusible cut-out should be added to protect the wire from a heavy, steady current, which may be maintained just below the opening point of the circuit breaker. The fuse requires a little time to heat, and therefore would not blow out with a momentary rise of current which might open the circuit breaker if set as low as necessary to protect the wire, which may be of a size only large enough for the figured amount of current under ordinary conditions of operation. If, however, in the case of motor wiring, the size of wire is 50 per cent above the figured size for the motor's average current, as it should be, then the introduction of a fusible cut-out in addition to the circuit breaker is unnecessary.

Insulating Joints should be made entirely of material that will resist the action of illuminating gases, and that will not give way or soften under the heat of an ordinary gas flame, or leak under a moderate pressure.

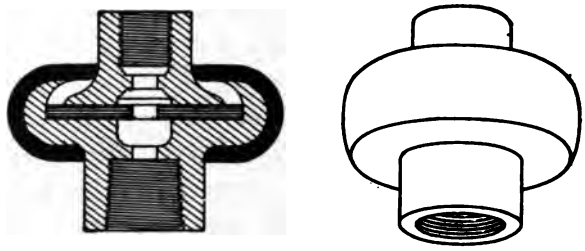


Fig. 12.

The Macallen Insulating Joint.

They should be so arranged that a deposit of moisture will not destroy the insulating effect, and should have an insulation resistance of at least 250,000 ohms between the gas pipe attachments, and be sufficiently strong to resist the strain they will be liable to be subjected to in being installed.

Insulating joints should not contain any soft rubber in their composition. The insulating material should be of some hard and durable material, such as mica. See Fig. 12.

Insulation Resistance. The wiring in any building should test free from grounds, *i. e.*, the complete installation should have an insulation between conductors and between all conductors and the ground (not including attachments, sockets, receptacles, etc.), of not less than the following:

Up to—	
5 amperes	4,000,000
10 amperes	2,000,000
25 amperes	800,000
50 amperes	400,000
100 amperes	200,000
200 amperes	100,000
400 amperes	50,000
800 amperes	25,000
1,000 amperes	12,500

All cut-outs and safety devices in place in the above.

Where lamp sockets, receptacles and electroliers, etc., are connected, one-half of the above will be required.

Knife Switches. Switches should be placed on all service wires, either overhead or underground, in a readily accessible place, as near as possible to the point where the wires enter the building, and arranged to cut off the entire current.

Knife switches should always be installed so that the handle will be up when the circuit is closed, so that gravity will tend to open rather than close the switch. They should never be single-pole except when the circuit which they control is carrying not more than six 16-candle-power lamps or their equivalent.

Double-pole switches are always preferable to single-pole, as they absolutely disconnect the part of the circuit out of use.

Flush Switches. Where gangs of flush switches are used, whether with conduit systems or not, the switches should be enclosed in boxes constructed of, or lined with, fire-resisting material.

Where two or more switches are placed under one plate, the box should have a separate compartment for each switch. No push buttons for bells, gas lighting circuits, or the like, should be placed in the same wall plates with switches controlling electric light or power wiring.

Snap Switches, like knife switches, should always be mounted on non-combustible, non-absorptive, insulating bases, such as slate or porcelain, and should have carrying capacity sufficient to prevent undue heating.

When used for service switches they should indicate at sight whether the current is "on" or "off." Indicating switches should be used for all work, to prevent mistakes and possible accidents. The fact that lights do not burn or the motor does not run is not necessarily a sure sign that the current is off.

Every switch, like every piece of electrical apparatus, should be plainly marked, where it is always visible, with the maker's name and the current and voltage for which it is designed.

On constant-potential systems, these switches, like knife switches, should operate successfully at 50 per cent overload in amperes with 25 per cent excess voltage, under the most severe conditions they are likely to meet with in practice. They should have a firm contact, should make and break readily, and not stop when motion has once been imparted to the handle. When this style of switch is used for constant-current systems, they should close the main circuit and disconnect the branch wires when turned "off;" should be so constructed that they will be automatic in action, not stopping between points when started; and should prevent an arc between the points under all circumstances. They should also indicate at sight whether the current is "on" or "off."

Incandescent Lamps. Table X is compiled from a series of careful tests on a number of incandescent lamps taken from a large stock at random.

Poor regulation of voltage results in more trouble with incandescent lamps and their users than any other fault in electric lighting service.

Some men act on the theory that so long as the life of a lamp is satisfactory, an increase of voltage, either temporary or permanent, will increase the average light. The fact is that when lamps are burned above their normal rating the average candle-power of all the lamps on the circuit is decreased.

Excessive voltage is thus a double error—it decreases the

TABLE X.

Incandescent Lamp Data.

Volts.	C. P.	Amp.	Watts Per Lamp.	Watts Per C. P.	Hot Res.
52	10	.67	35	3.50	77.61
"	16	1.08	56	"	48.14
"	20	1.34	70	"	38.80
"	24	1.62	84	"	32.09
"	32	2.15	112	"	24.18
"	50	3.36	175	"	15.47
"	100	6.73	350	"	7.72
"	150	10.09	525	"	5.15
104	10	.34	35	3.50	305.88
"	16	.54	56	"	192.59
"	20	.67	70	"	185.22
"	24	.81	84	"	128.39
"	32	1.08	112	"	96.29
"	50	1.68	175	"	61.90
"	100	3.36	350	"	30.95
"	150	5.05	525	"	20.59
110	10	.32	35	3.50	343.75
"	16	.51	56	"	215.68
"	20	.64	70	"	171.87
"	24	.76	84	"	144.73
"	32	1.02	112	"	107.84
"	50	1.59	175	"	691.82
"	100	3.18	350	"	34.59
"	150	4.77	525	"	23.06
220	16	.291	64	4.00	756.01
"	32	.582	128	"	379.31

total light of the lamps, and increases the power consumed. If increased light is needed, 20-candle-power lamps should be installed instead of raising the pressure. Their first cost is the same as 16-candle-power lamps; they take but little more current than 16-candle-power lamps operated at high voltage and give greater average light.

Increased pressure also decreases the commercial life of the lamp, and this decrease is at a far more rapid rate than the increase of pressure, as shown in the following table. This table

shows the decrease in life of standard 3.1-watt lamps due to increase of normal voltage.

Per Cent of Normal Voltage.	Life Factor.
100	1.000
101	.818
102	.681
103	.662
104	.452
105	.374
106	.310

From this table it is seen that 3 per cent increase of voltage halves the life of a lamp, while 6 per cent increase reduces the life by two thirds.

Intensity or Brilliancy. The average brilliancy of illumination required will depend on the use to which the light is put. A dim light that would be very satisfactory for a church would be wholly inadequate for a library and equally unsuitable for a ballroom.

The illumination given by one candle at a distance of one foot is called the "candle-foot" and is taken as a unit of intensity. In general, intensity of illumination should nowhere be less than one candle-foot, and the demand for light at the present time quite frequently raises the brilliancy to double this amount. As the intensity of light varies inversely with the square of the distance, a 16-candle-power lamp gives a candle-foot of light at a distance of four feet. A candle-foot of light is a good intensity for reading purposes.

Assuming the 16-candle-power lamp as the standard, it is generally found that two 16-candle-power lamps per 100 square feet of floor space give good illumination, three very bright and four brilliant. These general figures will be modified by the height of ceiling, color of walls and ceiling, and other local conditions. The lighting effect is reduced, of course, by an increased height of ceiling. A room with dark walls requires nearly three times as many lights for the same illumination as a room with walls painted white. With the amount of intense light available in arc and incandescent lighting, there is danger of exceeding "the limits of effective illumination" and producing a "glaring intensity" which should be avoided as carefully as too little intensity of illumination.

Distribution concerns the arrangement of the various sources of light and the determination of their candle-power. The object should be to "secure a uniform brilliancy on a certain plane, or within a given space. A room uniformly lighted, even though comparatively dim, gives an effect of much better illumination than where there is great brilliancy at some points and comparative darkness at others. The darker parts, even though actually light enough, appear dark by contrast, while the lighter parts are dazzling. For this reason naked lights of any kind are to be avoided, since they must appear as dazzling points in contrast with the general illumination."

The Arrangement of the Lamps is dependent very largely upon existing conditions. In factories and shops, lamps should be placed over each machine or bench so as to give the necessary light for each workman. In the lighting of halls, public buildings and large rooms, excellent effects are obtained by dividing the ceilings into squares and placing a lamp in the center of each square. The size of square depends on the height of ceiling and on the intensity of illumination desired. Another excellent method consists in placing the lamps in a border along the walls near the ceiling.

For the illumination of show windows and for display effects, care must be taken to illuminate by reflected light. The lamps should be so placed as to throw their rays upon the display without casting any direct rays on the observer.

The relative value of high candle-power lamps in comparison with an equivalent number of 16-candle-power lamps is worthy of notice. Large lamps can be efficiently used for lighting large areas, but in general a given area will be much less effectively lighted by high candle-power lamps than by an equivalent number of 16-candle-power lamps. For example, sixteen 64-candle-power lamps distributed over a large area will not give as good general illumination as sixty-four 16-candle-power lamps distributed over the same area. High candle-power lamps are useful chiefly when a brilliant light is needed at one point, or where space is limited and an increase in illuminating effect is desired.

The Relative Value of the Arc and Incandescent Systems of Lighting is frequently difficult to determine. Incandescent

TABLE XI.

Tested Fuse Wire.

CHASE-SHAWMUT CO.,
Boston.

Carrying Capacity. Amperes.	Standard Length. Inches.	Diameter in Mils.	Feet Per Pound.
¼	1½	10	2,700
½	1½	17	950
1	1½	20	670
1½	1½	23	510
2	1½	25	450
3	1½	27	370
4	1½	30	360
5	2	35	812
6	2	38	504
7	2	44	021
8	2	47	120
9	2	54	93
10	2	58	80
12	3	62	70
14	3	68	60
15	3	70	52
16	3	73	49
18	3	78	43
20	4	86	36
25	4	90	32
30	4	100	26
35	4	110	22
40	4	122	18
45	4	126	17
50	4	147	12.5
60	5	160	10.3
70	5	172	9.0
75	5	178	8.3
80	5	190	7.5
90	5	198	6.7
100	5	220	5.5

lamps have the advantage that they can be distributed so as to avoid the shadows necessarily cast by one single source of light. Arc lamps used indoors with ground or opal globes cutting off half the light, have an efficiency not greater than two or three times that of an incandescent lamp. Nine 50-watt, 16-candle-power lamps consume the same power as one full 450-watt arc lamp. It has been found that unless an area is so large as to require 200 or 300 incandescent lights distributed over it, arc lamps requiring equal total power will not light the area with so uniform a brilliancy.

Fuses should have contact surfaces or tips of harder metal, having perfect electrical connection with the fusible part of the strip.

The use of the hard metal tip is to afford a strong mechanical bearing for the screws, clamps or other devices provided for holding the fuse.

Fuses should be stamped with about 80 per cent of the maximum current they can carry indefinitely, thus allowing about 25 per cent overload before the fuse melts.

With naked open fuses of ordinary shapes and not over 500 amperes capacity, the maximum current which will melt them in about five minutes may be safely taken as the melting point, as the fuse practically reaches its maximum temperature in this time. With larger fuses a longer time is necessary.

The following table shows the minimum break distance, and the separation of the nearest metal parts of opposite polarity, for open-link fuses when mounted on slate or marble bases, for different voltages and different currents:

	Separation of nearest metal parts of opposite polarity.	Minimum break distance.
125 Volts or Less.		
10 amperes or less	¾ inch	¾ inch
11—100 amperes	1 inch	¾ inch
101—300 amperes	1 inch	1 inch
125 to 250 Volts.		
10 amperes or less	1½ inch	1¼ inch
11—100 amperes	1¾ inch	1¼ inch
101—300 amperes	2 inch	1½ inch

Fuse Terminals should be stamped with the maker's name or initials, or some known trade-mark.

Fuse Wire. Table XI shows the sizes of fuse wire and the approximate current-carrying capacity of each size.

Fuses have been known to blow out simply from the heat due to poor contact when nowhere near their current-carrying capacity had been reached. They should be so put up and protected that nothing will tend to rupture them except an excessive flow of current. No fuse of the larger sizes ever blew out without causing a greater or less fire risk.

Fuses blow out or melt from excessive heat, and nothing else, and are therefore not as instantaneous in their action as a circuit breaker, which is constantly cared for and kept clean. Central stations or large isolated plants subject to greatly varying loads should have their lines and generators protected by both fuses and magnetic circuit breakers as a double protection against excessive current.

The lengths of fuses and distances between terminals are important points to be considered in the proper installation of these electrical "safety valves." No fuse block should have its terminal screws nearer together than one inch on 50 or 100-volt circuits, and one inch additional space should always be allowed between terminals for every 100 volts in excess of this allowance. For example, 200-volt circuits should have their fuse terminals 2 inches apart, 300-volt 3 inches, and 500-volt 5 inches. This rule will prevent the burning of the terminals on all occasions of rupture from maximum current, and this maximum current means a "short circuit." Good contact is absolutely essential in the installation and maintenance of fuses. See that the copper tips to all fuses are well soldered to the fuse wire, and furthermore see that the binding screw or nut is firmly set up against this copper tip when the fuse is placed in circuit; a 100-ampere fuse can be readily "blown" by 25 amperes if the above precautions are not carried out. Poor contact in every case can cause a heating beyond the carrying capacity of the largest fuses. On the other hand, much damage can be done by using too short fuses and too large terminals, as the radiation of heat from the short piece of fuse wire to the heavy metal terminals and set screws or nuts can very easily raise the current-carrying capacity

of a fuse designed to carry 50 amperes to 100 amperes, or even more. All open-link fuses should be placed in cut-out cabinets when possible.

Cut-out Cabinets should be so constructed, and cut-outs so arranged, as to obviate any danger of the melted fuse metal coming in contact with any substance which might be ignited thereby.

A suitable box may be made of marble, slate or wood, strongly put together, the door to close against a rabbet so as to be perfectly dust tight, and it should be hung on strong hinges and held closed by a strong hook or catch. If the box is wood the inside should be lined with sheets of asbestos board about one-sixteenth of an inch in thickness, neatly put on and firmly secured in place by shellac and tacks. The wires should enter through holes bushed with porcelain bushings, the bushings tightly fitting the holes in the box, and the wires tightly fitting the bushings (using tape to bind up the wire, if necessary), so as to keep out the dust.

The Enclosed Fuse, or "Cartridge Fuse" (see Fig. 13), consists of a fusible strip or wire placed inside of a tubular holding jacket filled with porous or powdered insulating material through which the fuse wire is suspended from end to end and which surrounds the fuse wire. The wire, tube and filling are made into one complete, self-contained device with brass or copper terminals or ferrules at each end, the fuse wire being soldered

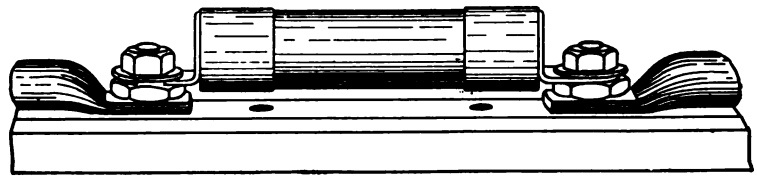


Fig. 13.
Enclosed Fuse.

to the inside of the ferrules. When an inclosed fuse "blows" by excess current or short circuit the gases resulting are taken up by the filling, the explosive tendency is reduced and flashing and arcing are eliminated.

Incandescent Lamps in Series Circuits should be wired with

DIRECT CURRENT SERIES LAMP

DIRECT CURRENT SERIES LAMP

ALTERNATING CURRENT LAMP

Mechanism of "Wood" Enclosed Arc Lamps

the same precaution as for series arc lighting and each lamp should be provided with an automatic cut-off.

Each lamp should be suspended from an approved hanger board by means of a rigid tube, to prevent the wires from constant swinging.

No electro-magnetic device for switches and no system of multiple, series, or series-multiple lighting in this class of work should be used. Under no circumstances should incandescent lamps in series circuits be attached to gas fixtures, as the high voltage necessarily employed in this class of lighting should be kept as far as possible from gas piping, which is so thoroughly grounded or likely to be.

When incandescent lamps are used for decorative purposes, as in the use of miniature colored lamps, and it is necessary to run two or more in series, permission should always be secured, in writing, from the Inspection Department having jurisdiction.

Arc Lamps should be carefully isolated from inflammable material, should be provided at all times with a glass globe surrounding the arc and securely fastened upon a closed base. No broken or cracked globes should be used, as they are designed to prevent hot bits of carbon from falling to the floor should they fall from the carbon holder. All globes for inside work should be covered with a wire netting having a mesh not exceeding one and one-quarter inches, to retain the pieces of the globe in position should the latter become broken from any cause. A globe thus broken should be replaced at once. When arc lamps are used in rooms containing readily inflammable material they should be provided with approved spark arresters, which should be made to fit so closely to the upper orifice of the globe that it would be impossible for any sparks thrown off by the carbons to escape. It is safer to use plain carbons and not copper-plated ones in such rooms, or better still, an enclosed arc lamp, one having its carbons enclosed in a practically tight glass globe which is inside the outer globe. Where hanger-boards are not used arc lamps should be hung from insulating supports other than their conductors.

All arc lamps should be provided with reliable stops to prevent carbons from falling out in case the clamps become loose,

and all exposed parts should be carefully insulated from the circuit. Each lamp for constant-current systems should be provided with an approved hand switch, and also an automatic switch that will shunt the current around the carbons, so that the lamp will thus cut itself out of circuit should the carbons fail to feed properly. If the hand switch is placed anywhere except on the lamp itself, it should comply in every respect with the requirements for switches on hanger-boards as described under the latter heading.

Arc Light Wiring. All wiring for high-potential arc lighting circuits should be done with "Rubber-Covered" wire. The wires should be arranged to enter and leave the building through an approved double-contact service switch, which should close the main circuit and disconnect the wires in the building when turned "off." These switches should be so constructed that they will be automatic in their action, not stopping between points when started, and preventing arcing between points under any circumstances, and should indicate plainly whether the current is "on" or "off." Never use snap switches for arc lighting circuits. All arc light wiring of this class should be in plain sight and never enclosed except when required, and should be supported on porcelain or glass insulators which separate the wires at least one inch from the surface wired over. The wires should be kept rigidly at least eight inches apart, except of course within the lamp, hanger-board, or cut-out box or switch. On side walls the wiring should be protected from mechanical injury by a substantial boxing retaining an air space of one inch around the conductors, closed at the top (the wires passing through bushed holes), and extending not less than seven feet above the floor. When crossing floor timbers in cellars or in rooms, where they might be exposed to injury, wires should be attached by their insulating supports to the under side of a wooden strip not less than one-half an inch in thickness.

Arc Lamps on Low-Potential Circuits should have a cut-out for each lamp or series of lamps. The branch conductors for such lamps should have a carrying capacity about 50 per cent in excess of the normal current required by the lamp or lamps, to

provide for the extra current necessary when the lamps are started, or, should a carbon become stuck, to prevent over-fusing the wires. If any resistance coils are necessary for adjustment or regulation, they should be enclosed in non-combustible material and be treated as sources of heat; it is preferable that such resistance coils be placed within the metal framework of the lamp itself. Incandescent lamps should never be used for resistance devices. These lamps should be provided with globes and spark arresters, as in the case of arc lamps on high-potential series circuits, except when the enclosed arc lamps are used.

Economy Coils, or compensator coils, for arc lamps should be mounted on glass or porcelain, allowing an air space of at least one inch between frame and support, and in general should be treated like sources of heat.

Hanger-Boards should be so constructed that all wires and current-carrying devices thereon will be exposed to view and thoroughly insulated on non-combustible, non-absorptive insulating substance, such as porcelain.

All switches attached to the hanger-board should be so constructed that they will be automatic in their action, cutting off both poles to the lamp, not stopping between points when started, and preventing an arc between points under all circumstances.

Electric Heaters should always be treated as sources of heat and kept away from inflammable materials. Each heater should have a cut-out and indicating switch, and all attachments from the feed wires to the heater should be kept in plain sight, easily accessible and protected from interference. Each heater should have a name-plate giving the maker's name and the normal capacity in volts and amperes.

Approved Apparatus and Supplies. Every article or fitting intended for use in electrical wiring or construction or in connection therewith should, before being manufactured or placed upon the market, be examined and approved by the Underwriters' National Electric Association for use under the rules and requirements of the National Board of Fire Underwriters and placed upon their official list of "approved" electrical fittings.

Any new article, therefore, or modification of an old article,

intended to be placed in general electrical use, should first be sent for examination and test to the laboratory of the Electrical Bureau of the National Board of Fire Underwriters, 67 East Twenty-first street, Chicago, Ill.

If the article is approved it will be placed upon the list of fittings, which list is revised quarterly. When buying electrical supplies of any description make sure that they have been approved. If there is any question about it, make your supply dealer give you a guarantee that they will be approved by the Fire Underwriters' Inspector if installed in accordance with the rules and requirements of the National Board of Underwriters.

Electrical Inspection. The principal points regarding the safe installation of dynamos, motors, outside and inside wiring, as required by the insurance underwriters, have been set forth in this paper. There will probably arise questions which cannot be settled by reference to the suggestions herein contained, and therefore a great deal has to be left to the judgment of the constructing engineer and inspector. In every such case the Inspection Department having jurisdiction should be consulted with perfect assurance that nothing unreasonable will ever be demanded in the way of special construction.

Every piece of wiring or electrical construction work, whether open or concealed, should be and usually is inspected, and notice, therefore, should always be sent by the contractor or engineer to the board having jurisdiction, immediately upon completion of any work.

Negligence in this matter has frequently caused floors to be torn up when doubtful work has been suspected, and at the cost of the parties who installed the wiring.

The insurance inspector cannot order any piece of wiring taken out or altered, but always reports whether or not the plant is installed in a manner which will reduce the fire risk to a minimum. If the inspector has occasion to recommend any changes which he considers for the safety of the building, and such changes are not immediately made, he recommends that the insurance rate on the building be so raised that it will, in the end, be found advisable to attend to his suggestions, which are in every case reasonable.

BATTERY OF "CHLORIDE ACCUMULATORS"

STORAGE BATTERIES.

Storage or secondary batteries, also called accumulators, consist of cells in which a chemical change is brought about by passing an electric current through them, thereby rendering them capable of giving back electrical energy by discharging them until they return to their original chemical condition.

Ordinarily, a storage battery consists, essentially, of two sets of plates suspended in a chemical solution. The plates are of metal or metallic oxide, and the solution is incapable of acting upon them until an electric current is passed from one plate to the other. This current decomposes the electrolyte; one of its constituent elements or radicals goes to one plate, and the remaining constituent to the other, so that when the passage of the current ceases there are two chemical elements or radicals with a tendency to unite, and upon combination the energy evolved appears as an electric current, which flows in the opposite direction to the charging current. This flow of current continues until the cell is restored to its original condition; when this occurs the cell is said to be discharged.

A Primary Cell is one in which electrical energy is produced by the chemical action of one or two solutions on the plates of the cell. When the solutions or plates are exhausted, they are *not* restored to their original condition by the passage of an electrical current.

This reversibility or regeneration is the fundamental difference between storage and primary cells.

An Electrolyte is a chemical compound, capable of acting as an electrical conductor, and while so acting, undergoes chemical decomposition. This phenomenon is called electrolysis.

For example, when hydrochloric acid is decomposed by electrical energy, it is decomposed into the elementary gases hydrogen (H) and chlorine (Cl). The chemical formula for this action is,

$$2H\,Cl + \text{Electrical energy} = Cl_2 + H_2.$$

When sulphuric acid is electrolyzed, it is at first split up into hydrogen (H_2) and the radical sulphion (SO_4); the latter combines with the water of solution present and reforms sulphuric acid (H_2SO_4) and oxygen is liberated. The chemical equations for the above primary and secondary reactions are:

$$2H_2O + 2H_2SO_4 + \text{Electrical energy} = 2H_2 + 2SO_4 + 2H_2O$$
$$2H_2 + 2SO_4 + 2H_2O = 2H_2 + 2H_2SO_4 + O_2.$$

The modern theory of electrolysis assumes that in an electrolytic solution there are always free ions which wander around promiscuously, until the application of an electric current directs their wanderings into certain definite directions.

Any salt dissolved in water is ionized, that is, some portion is separated into the two component parts of the salt.

When certain metals such as potassium or sodium are free in an ionized solution they are said to be in an allotropic state, and when the current is passed through the solution, the metal is freed from its allotropic state, and will in such cases, form hydrates, (KOH), (NaOH). The theory also states that the conductivity of electrolytes is due to the presence of these ions, and that the non-ionized portion does not conduct.

In 1802, soon after the invention of the primary cell by Volta, Gautherot demonstrated the fact that platinum wires, after being used to electrolize saline solutions, were able to produce secondary currents. Volta, Ritter, Davy and others noted similar effects, the phenomenon being what is commonly called polarization. In 1859 Planté undertook a series of experiments with the object of studying and magnifying this effect and finally developed the Planté type of storage battery; nearly all successful types of storage batteries of the present day are based upon the Planté cell.

Types of Storage Batteries:

Planté,
Faure,
Combination of Planté and Faure,
Non-lead.

PLANTÉ BATTERY.

This cell was originally made by placing two plates of metallic lead in a vessel containing dilute sulphuric acid. These plates were connected to an electric generator, and a current sent through the cell, which decomposed the electrolyte and oxidized the positive plate. The cell was then discharged; but the energy obtained was very small, since the action was confined to the immediate surface of the plates. By repeated charging and discharging first in one direction and then in the other, the oxidation penetrated deeper and deeper into both plates, thus increasing the storage capacity of the cell.

The chief difficulty with the Planté battery was the great length of time required for "forming" the plates, which as just explained consists in converting the surface of the plates into active materials, by repeated chargings and dischargings. This takes a long time and is expensive, as it requires a large consumption of electrical energy. Later on in his investigations, Planté hastened this forming process by pickling the plates in dilute nitric acid, then washing them in a 10 per cent sulphuric acid solution, after which they were electrically formed. An inherent difficulty with the Planté system is that plates well adapted to the forming process are difficult to make.

In 1881 Faure devised the method of pasting the lead oxide or active material directly upon the plates. This largely avoids the tedious forming process; but the plates thus produced are not as durable as the Planté elements, being more likely to disintegrate and buckle, because the paste is not an integral part of the plate and there is considerable difference in the coefficients of expansion of lead and of the oxide.

Innumerable forms of storage batteries have been invented, and many of them have been exploited, in which copper, zinc, iron and other metals or elements instead of lead were used; but almost all of those now being manufactured and used commercially are of some lead type. Such being the case, it is safe to assume or infer, that this lead combination possesses distinctive features not present in the other combinations; and upon investigation, it is apparent that these features are that the electrodes, the active materials and the compounds formed from them are,

under every normal condition of use, insoluble in the electrolyte employed.

In every other form of battery now on the market, one or even both of the electrodes or materials formed on them are soluble in the electrolyte, and this solubility is detrimental to the storage power and life of the cell.

General Principles of the Storage Battery. Any primary battery will act as a storage battery provided its chemical action is reversible. The ordinary gravity cell, for example, may be regenerated by sending a current through it in the direction opposite to that produced by it. The zinc sulphate and the metallic copper are thus reconverted into metallic zinc and sulphate of copper respectively, the chemical action being

$$ZnSO_4 + Cu + \text{Electricity} = Zn + CuSO_4,$$

which is exactly the reverse of the action in the primary cell. There are, however, practical difficulties in the continued recharging of a spent gravity cell, due to the ultimate mixture of the sulphate solutions and the copper salt reaching the negative electrode, where it is deposited and sets up destructive local action.

In some forms of primary cells, the chemical action liberates a gas that escapes, so that the action is obviously irreversible.

Chemical Action in Lead Storage Batteries. The exact nature of the chemical changes which occur in lead batteries, is not yet fully established. Planté believed the charging action to consist in the formation of peroxide of lead (PbO_2) on the positive plate, and metallic lead on the negative, which were converted into lead oxide (PbO) on both plates by the discharge. Some authorities still maintain this to be the chief reaction; but it has been shown by Gladston and Tribe, and corroborated by subsequent investigations, that the formation of lead sulphate plays an important part.

The probable reaction may be represented as follows:

	Positive Plate.		Electrolyte.		Negative Plate.
Charged Condition	PbO_2	+	$2H_2SO_4$	+	Pb
Discharged "	$PbSO_4$	+	$2H_2O$	+	$PbSO_4$
Charging Current			⟫⟶		
Discharging Current			⟵⟪		

According to the above equations, the active material on both plates is converted into lead sulphate when the battery is discharged. The reasons for believing this to occur are: *first*, chemical analysis shows that lead sulphate exists in the discharged plate, *second*, the density of the electrolyte decreases during the discharge of the cell, corresponding to the consumption of sulphuric acid and the formation of water as shown in the above reactions, *third*, on the thermo-chemical grounds, the combination of lead and oxygen as lead oxide (PbO) does not evolve sufficient energy to account for the E. M. F. or voltage produced.

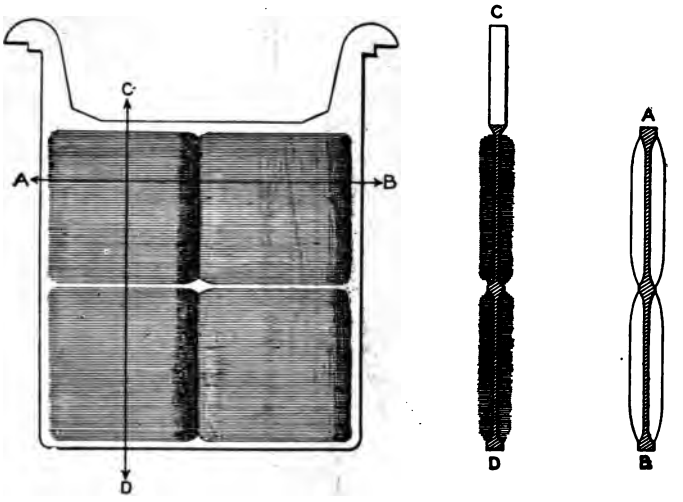


Fig. 1. Gould Storage Battery Plate.

Storage Batteries of the Planté Type. It was noted that the serious objection to the Planté battery was the great length of time necessary to form the plates, and how Planté treated them with nitric acid to hasten this action. Other methods are used to obtain a quickened formation, and are tabulated as follows:

1. *Mechanical Action:* Laminated plates, made up of lead ribbons. The surface of the plate is grooved with some forming tool. Built up of lead wires, etc.
2. *Chemical:* Treating the plates in some pickling bath, to produce initial oxidation.
3. *Electrolytic:* Forming a plate of some compound of lead or an alloy, and either reducing the compound or eating the foreign matter away, leaving a porous lead plate.

The Gould Storage Battery. This battery is made by the Gould Electric Storage Battery Company of N. Y., and the plates are produced by a combination of the first and third methods. The plates or blanks are placed in steel frames and given a reciprocating motion between two revolving shafts which carry grooving discs, giving the plates a surface as shown in Fig. 1. No lead is removed by this process but the surface is ploughed up. It is then subjected to electro-chemical treatment to form the active material. The completed cells range in size from a cell of three plates 3 inches by 3 inches, to one of one hundred and five plates each 15.5 inches by 31 inches, and in capacity in ampere-hours from five to seventeen thousand.

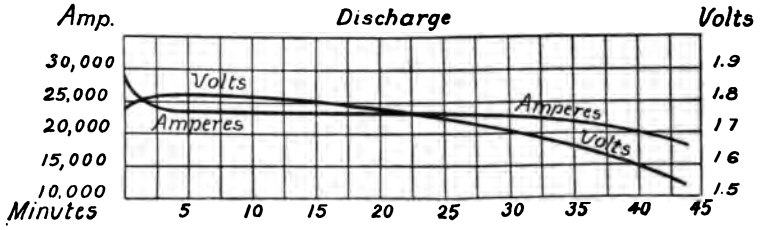


Fig. 2. Discharge Curve of a Gould Type "T" Battery.

The curves shown in Fig. 2 are reproductions of curves obtained from tests of one of their type — T batteries, plates each 15.5 inches by 31 inches, and 101 in number, made at the Pan American Exposition. The weight of this battery complete is about seven thousand and fifty pounds.

The Crompton-Howell Battery. A standard form successfully used in England, is of the Planté type, the plates being composed of a porous crystalline lead, made according to method 3 (see page 5) and afterwards "formed" by repeated charges and discharges. The regular dimensions of the plates are 9 inches by 9 inches by $\frac{1}{4}$ inch, and the different sizes of cell are made up by varying the number of plates. A cell of this type with sixty-one plates can maintain a discharge of 1000 amperes for thirty minutes without a serious fall in potential.

FAURE TYPES OF STORAGE BATTERY.

As has been stated, the difficulty with the Faure type is the natural tendency to disintegrate or buckle. Various methods to

increase the permanency of the adhesion of the active material have been suggested of which the most important are as follows :

1. Plates are grooved, roughened, or " pocketed."

2. Plates are entirely perforated, the holes being circular, or rectangular, and varying in cross section; some have a uniform section through the grid A, Fig. 3, others are contracted at the

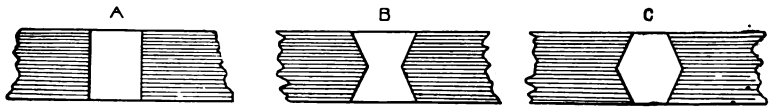


Fig. 3. Different Cross Sections of Faure Plate Perforations.

center B and again they may be expanded at the center of the grid C.

3. The active materials may be enclosed in either a conducting or non-conducting cage.

4. The plates may be made up entirely of active material.

Faure cells usually have a greater weight efficiency than Planté types because the proportion of active material may be made greater.

The E. P. S. Battery is one of the most important of the

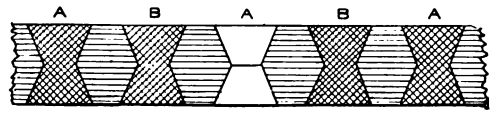


Fig. 4. Section of E. P. S. Battery Plate.

Faure type, its name being the initials of the Electric Power Storage Company by which it is manufactured in England. It is sometimes called the Faure-Sellon-Volckmar cell, being made under the combined patents of these and several other inventors.

The plates consist of lead grids cast in an iron mold, and have the cross-section shown in Fig. 4. The later types have a thin perforated strip of metal (lead) running across each opening midway between the edges. The holes A in the grid are completely filled with a paste of red lead or minium (Pb_3O_4) and dilute sulphuric acid for the positive, while the paste for the negative

consists of minium, or litharge (PbO) and dilute sulphuric acid or a magnesium sulphate solution. These pastes are pressed into the grids and dried.

The plates are hardened in dilute sulphuric acid, after which they are ready for forming. A strong current of 48 hours' duration is required for the positive plate and twenty-four hours is required for the formation of the negative plate. To prevent short circuiting after the cells are set up, the plates have glass rod separators placed between them.

The E. P. S. batteries are made in many different sizes and types, of which the L type is a good example, being used extensively in isolated plants. Data of this type are as follows:

E. P. S. ACCUMULATOR, L. TYPE.

No. of Plates.	Maximum Normal Charge or Discharge Rate.	Capacity Ampere Hours.	Approximate External Dimensions.			Weight Complete with Acid Wooden Cell.
			Length.	Width.	Height.	
7	13 amperes	130	5½ in.	13½ in. for wooden and 12 for glass cell.	18 in. for wooden and 13½ for glass cell.	74 lbs.
11	22 "	220	8			107 "
15	30 "	330	9½			143 "
23	46 "	500	14½			228 "
31	60 "	660	19			286 "

One of the smaller types of the E. P. S. battery is used extensively in England in electric vehicle work.

The Exide Battery is manufactured by the Electric Storage Battery Co., of Philadelphia, chiefly for electric vehicle duty. The plates are of the Faure type, and consist of lead-antimony grids (about 5 per cent antimony) pasted with oxides of lead.

The grid for the positive plate is of the cage type, consisting of thin vertical ribs, the edges of which are flush with the faces of the plate, and connected by small bars of a triangular cross section; the bars on one face are staggered with respect to those on the other side. This finished form is then pasted up with red lead (Pb_3O_4) and formed in the usual way; the thickness of the

finished plate is about $\frac{7}{32}$ inch. From this description it is evident that the plate is made up in accordance with method 3 described on page 7, the enclosing cage being of conducting material. The active material is in the form of rectangular pencils extending from the top of the plate to the bottom. The thin flat ribs are on two sides of these pencils and the triangular cross pieces are imbedded in the other two sides which constitute the faces of the plates. The Exide cell is shown in Fig. 5.

Fig. 5. Exide Battery.

The negative plate consists of a thin antimony lead sheet, with a comparatively heavy frame of cast lead. The body of the sheet is perforated at regular points and very close together. These perforations are not actual punchings (being made by a tool which does not remove the material) but are simply holes torn in the plate leaving the material around the hole in ragged projections which curve back towards the sheet, and form as it were a series of hooks. These projections are formed on both sides of the plates.

The grid is then pasted with litharge (PbO) on both faces; it is held to the plate by the "hooks" as well as being "riveted"

by passing through the holes which the projections surround. The thickness of this finished plate is about $\frac{3}{16}$ inch.

When assembled, the plates are placed in rubber jars of

DATA SHEET EXIDE CELLS.

TYPE.	—M. V.—							—P. V.—			
Number of Plates.	7	9	11	13	15	17	19	5	7	9	11
Discharge in Amps for 4 Hours.	21	28	35	42	49	56	63	12	18	24	30
Size of Plates.											
Length (inches).	5¾	same	same	same	same	same	same	4 11/16	same	same	same
Height (inches).	8¾	same	same	same	same	same	same	8¾	same	same	same
Outside Measures of Rubber Jars.											
Width (inches).	2 7/8	3¼	4¼	4 11/16	5 1/16	6¼	7 1/16	1 13/16	2 5/16	3¼	4¼
Length (inches).	6 3/16	same	same	same	same	6	6	5 7/16	same	same	same
Height (inches).	11½	same	same	same	same	11	11	11½	same	same	same
Weight in Pounds.											
Elements.	15¾	20¾	25¾	30¼	35	40	44¾	9¼	13¼	17¼	21¾
Electrolyte.	2¾	3¼	4¼	6¼	7	8	8¾	1¼	2¼	3	4¼
Complete Cell.	19¾	25¾	31¼	38¾	44¾	50	56	11¾	17¾	21¾	27¾

dimensions as above, and separated from each other by wooden partitions. In addition a perforated rubber sheet is placed against the faces of the positive plates.

The brougham or hansom battery of this type of cell consists of 44 cells of TV–9 size, having four positive and five negative plates. The weight of this outfit complete with tray is about

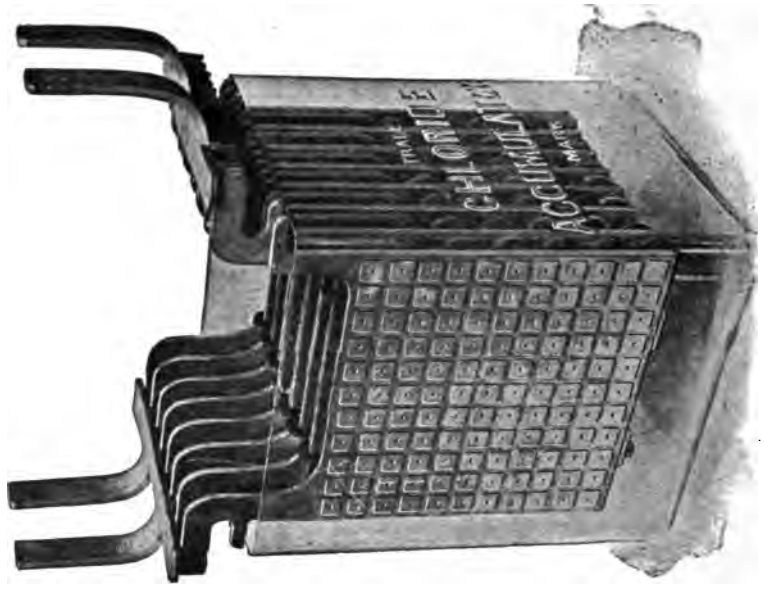
1659 pounds, the capacity 156 ampere hours (4 hour, 39 ampere rate), the average voltage during discharge about 1.98 volts per cell or 87 volts for 44 in series, the total watt-hour output being therefore 13,572, or 8.18 per pound.

COMBINATIONS OF PLANTÉ AND FAURE TYPES.

The Chloride Battery, manufactured by the Electric Storage Battery Company of Philadelphia and allied companies in England, France and Germany, is a compromise between the Planté and Faure types, the positive being of the Planté type, and the negative of practically the Faure type.

The principal features in the manufacture of this battery are as follows: The first step is the production of finely divided lead, which is made by directing a blast of air against a stream of the molten metal, producing a spray of lead which upon cooling falls as a powder. This powder is dissolved in nitric acid (HNO_3) and precipitated as lead chloride ($PbCl_2$) on the addition of hydrochloric acid (HCl). This chloride washed and dried forms the basis of the material which afterwards becomes active in the negative plate B, Fig. 6. The lead chloride is mixed with zinc chloride, and melted in crucibles, then cast into small pastiles or tablets about $\frac{3}{4}$ inch square and of the thickness of the negative plate, which according to the size of the battery varies from $\frac{1}{4}$ inch to $\frac{5}{16}$ inch. These tablets are then put in molds and held in place by pins, so that they clear each other by .2 inch and are at the same distance from the edges of the mold. Molten lead is then forced into the mold under about seventy-five pounds pressure, completely filling the space between the tablets. The result is a solid lead grid holding small squares of active material. The lead chloride is then reduced by stacking the plates in a tank containing a dilute solution of zinc chloride, slabs of zinc being alternated with them. This assemblage of plates constitutes a short-circuited cell, the lead chloride being reduced to metallic lead. The plates are then thoroughly washed to remove all traces of zinc chloride.

A new form of negative plate has recently been designed which promises to replace the chloride type just discussed. It consists of a "pocketed" grid, the opening being filled with a litharge paste; this is then covered with perforated lead sheets,



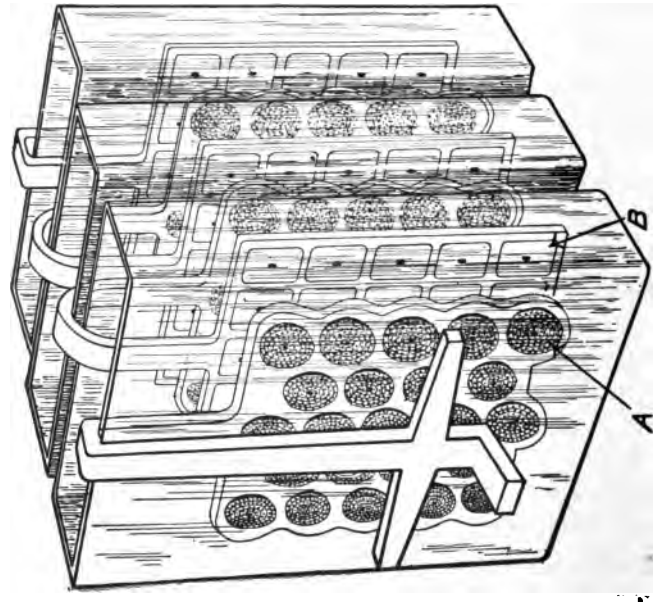


Fig. 6 The Chloride Cell, Showing Plate Construction.

which are soldered to the grid. The positive plate (A, Fig. 6) is a firm grid, composed of lead alloyed with about 5 per cent of antimony, about $\frac{7}{16}$ of an inch thick, with circular holes $\frac{25}{32}$ of an inch in diameter, staggered so that the nearest points are .2 of an inch apart. Corrugated lead ribbons $\frac{7}{16}$ of an inch wide are then rolled up into close spirals of $\frac{25}{32}$ of an inch in diameter, which are forced into the circular holes of the plate.

By electro-chemical action, these spirals are formed into active material, the process requiring about thirty hours; at the same time the spirals expand so that they tend to fit still more

DATA CHLORIDE BATTERY.

TYPES.	B.	C.		BT.	CT.	PT.	D.		E.		F.		G.		H.	
Size of Plate in inches	3x3	4⅜x4		3x4	5x5	8¾x5	6x6		7¾x7¾		11x10½		15½x15½		15½x30¾	
Number of plates	3	3	7	2	2	2	3	13	5	15	9	27	11	75	21	75
Discharge in Amperes — For 8 hours	⅝	1½	3¾	¾	1½	3	2½	15	10	35	40	130	100	740	400	1480
Discharge in Amperes — 5	⅞	1¾	5⅝	1	2	4½	3½	21	14	42	56	182	140	1036	560	2072
Discharge in Amperes — 3	1¼	2½	7½	1½	3	6	5	30	20	70	80	260	200	1480	800	2960
Discharge in Amperes — 1									40	140	160	520	400	2960	1600	5920
Normal Charge Rate	⅝	1½	3¾	¾	1½	3	2½	15	10	35	40	130	100	740	400	1480
Outside dimensions of glass jars, inches. — Width	2½	3½	5⅛	1⅞	2½	2½	3½	11	5½	11	9	No glass jars for these large sizes.				
Outside dimensions of glass jars, inches. — Length	4	5½	5½	3¾	6½	6	7⅞	8½	9½	9½	12⅝					
Outside dimensions of glass jars, inches. — Height	6½	7⅛	7½	6¾	8	12	9½	9½	11⅝	11⅝	15½					
Outside dimensions for lead lined wooden tanks. — Width											11⅝	28⅝	15¾	73½	26¼	73½
Outside dimensions for lead lined wooden tanks. — Length											15	15	19¾	21½	21½	21½
Outside dimensions for lead lined wooden tanks. — Height											17¾	17¾	23	24⅞	42⅞	43⅞
Wht. of cell complete with acid and glass jar (lbs)	5½	10½	20	4½	9½	18	20	64	48¾	112						
Ditto. Lead lined tanks.											217	531	526	3086	1817	5786

closely in the grids. This form of positive is that known as the Manchester Plate.

In setting up the cells, the plates are separated from each other by special cherry wood partitions, the perforations being connected by vertical grooves to facilitate the rising of the gases. Sometimes glass rods are used as separators.

The table gives the data of the various types and sizes of cells. To save space only the smallest and largest sizes of each type are given. but in all cases intermediate sizes are made with

every odd number of plates. The capacities, weights, etc. are of course nearly proportional to the number of plates.

The smaller sizes are provided with either rubber or glass jars, and the larger ones, from F up, with lead-lined tanks.

The Tudor Cell is very extensively used in Europe, and to some extent in this country, although it is no longer manufactured here. The American patent rights are controlled by the Electric Storage Battery Company.

The plates consist of rolled, grooved sheets as shown in Fig. 7, A being the hollows or grooves into which the paste is set and B the lead frame. The thickness of the plate between opposite grooves is about .12 inch for the positive, and about .06 inch for the negative. The width of grooves on the positive plate is also about .12 inch, while on the negative it is about .08 inch. The grooves are first coated with a thin layer of peroxide of lead (PbO_2) by electrolysis, and then packed with the oxides as required; the plates are then rolled to "fix" the paste. This treatment of the grid with an electrolytic bath before applying the active material, is covered by U. S. patent No. 413,112.

TUDOR CELLS.

Type.	Available Capacity.	Maximum Current in Amperes.		Dimensions of Cells in Centimeters.			Total Weight.
	Amp. Hours.	Charge.	Discharge.	Length.	Width.	Height.	Kgms.
I	26	6	8	12	21	35	10
V	91	21	28	30	21	35	30
X	270	54	72	42	42	55	110
XIV	630	126	168	74	42	55	230

In addition to those given above, all of the intermediate sizes are made.

A battery of larger cells is in use in the Head Place Station of the Edison Company of Boston, Mass., a description of which is given in the Electrical Engineer (N. Y.) of Sept. 18, 1895. The plant contains two batteries of 72 cells each. Each cell consists of a lead-lined wooden box, 3 feet 10 inches long, 3 feet 4 inches wide, and 3 feet deep, in which are suspended 18 positive

and 19 negative frames. Each positive frame is composed of 16 plates 7 inches square ; while each negative frame has 4 plates 14 inches square, thus giving an enormous surface in each cell. The plates are secured in their respective frames by lead strips. The frames are held in position about $\frac{1}{2}$ inch apart by vertical glass tubes, and rest upon thick glass plates placed on edge in the bottom of the cell; the frames being thus raised 6 inches above the floor of the cell. It is said that these two batteries combined are capable of supplying 6,600 amperes at 110 volts for $1\frac{1}{4}$ hours, which would usually cover the period of very heavy load. This is an output of 726 kilowatts, or nearly 1,000 horse-power for $1\frac{1}{4}$ hours, being a remarkably high discharge rate.

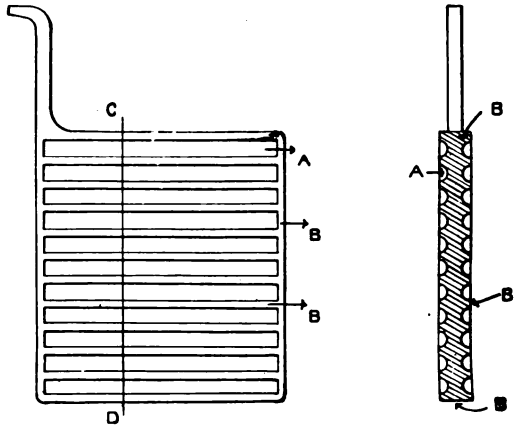


Fig. 7. The Tudor Battery Plate.

It is recommended for central-station use, particularly where the rate of discharge is great, as, for example, when the total time of discharge is only $1\frac{1}{2}$ to 4 hours. For this work the negative plates are of the Chloride type, the positives being the heavy Tudor plates described above.

Lithanode. Mr. Desmond Fitzgerald has made storage batteries with a positive plate consisting entirely of active materials made up of litharge (PbO) mixed with ammonium sulphate $(NH_4)_2\ SO_4$ which he pressed into the required shapes. This plate is converted into peroxide by chemical treatment. The negative of this cell consists of the ordinary lead plate. While this cell has an exceedingly high weight efficiency it is not of

much commercial importance, though used considerably in laboratory work.

It is the tendency in Europe to make the positive plate of the Planté form and the negative of the Faure or pasted type. The reason for this is that the Planté form is hard to make, and as the activity is small on the negative the pasted plate is good enough.

The practice in lead batteries is to make the negative plate of greater capacity than the positive, as the charging and discharging of a cell in service tends to produce or form more active material on the positive plate, whereas the negative plate is made to decrease, so that allowance for this is made as above stated.

Storage Batteries Containing Metals other than Lead. It has already been stated that almost any primary cell will act more or less perfectly as a secondary cell; as, for example, the common gravity battery. A great many have been devised in which the lead in one or both of the plates has been replaced by some other metal. For example, Reynier made the negative plate of zinc instead of lead, this zinc in discharging being converted into zinc sulphate, which dissolved in the electrolyte. The substitution of zinc for lead secures an increase in initial E. M. F. from 2.2 to 2.5 volts, and also allows of a considerable reduction in weight; since for the storage of a given amount of energy the weight of the zinc required is much less than that of the equivalent lead. A difficulty with this type of cell is the formation of "trees" of zinc on the negative plate during the charging process, which are likely to fall off or extend across to the positive plate, thus short-circuiting the cell.

Another difficulty is the difference in density of the solution between the top and bottom of the plates, the tendency being to exhaust the zinc sulphate from the upper portion of the liquid during charging. In order to avoid this trouble the plates have been arranged horizontally, so that the density would be uniform for each plate; but the difficulty then arises that the gases which form to a certain extent in almost all batteries collect between the plates and interfere with the chemical action and the passage of the current.

A similar type of cell has been manufactured by the Union Electric Company of New York, in which the negative plates con-

sist of thin sheet copper covered with an amalgam of zinc, and the positive plates are made up of laminæ of lead held together by leaden rivets and perforated with numerous small holes, these positives being formed by the Planté process.

Waddell-Entz Accumulator. The copper-alkali-zinc primary battery of Lalande, Chaperon and Edison being reversible in action, can be used as a storage battery. Waddell and Entz have constructed accumulators on this principle. When discharged, the positive plate consists of porous copper; on charging the electrolyte is decomposed, metallic zinc being deposited on the negative plate, the porous copper of the positive plate is oxidized, and the liquid

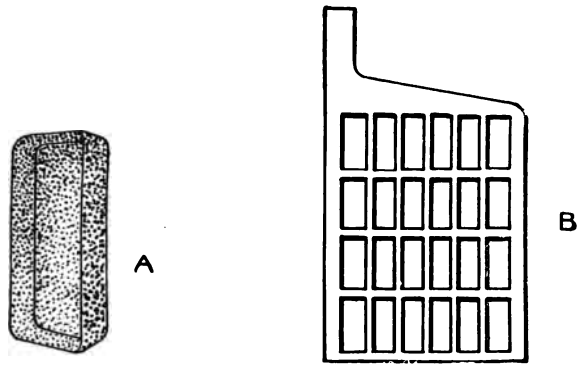


Fig. 8. Construction of Edison Battery Plate.

becomes converted into a solution of caustic potash (potassium hydrate).

This storage battery has been used with considerable success for traction purposes, but its E. M. F. is so low, being only about .7 volt, that it would require 170-180 cells for the ordinary 119 volt electric-lighting circuit, allowing for loss of potential in the battery and conductors. This number is three times as great as is required with the lead battery. This is a serious objection in this or any other low voltage cell.

The Edison Storage Battery manufactured by the Edison Storage Battery Company of Newark, N. J., consists of a positive plate of super-oxide of nickel (NiO_2) and a negative plate of iron, suspended in about a 20 per cent solution of caustic potash (KOH).

The mechanical construction of both plates (positive and negative) is the same, and the grids are made of nickel-plated steel, shaped as represented at B, Fig. 8. Each opening in the grid is filled with a perforated shallow pocket A or box of nickel-plated steel which contains the active material, and projects out beyond the body of the grid.

The active material is made up in the form of briquettes; one briquette being placed in each pocket. A perforated cover of nickel steel is placed over each pocket. After the plates are fully assembled they are subjected to a pressure of about 100 tons,

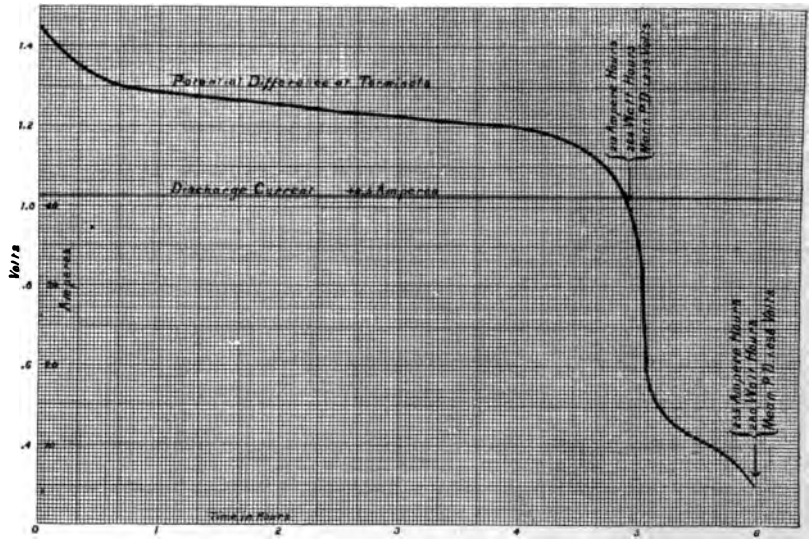


Fig. 9. Curve of Voltage of Edison Cell During Discharge.

which firmly forces all parts into a practically solid mass, making good electrical contact between the pockets and the grid, at the same time turning the edges of the pockets over their respective covers. The active material or briquette consists of a finely divided compound of nickel mixed with about an equal amount of flaked graphite, for the positive plate, and for the negative plate it consists of a finely divided compound of iron, with an equal amount of flaked graphite. This graphite has no chemical connection with the action of the cell but is used simply to increase the conductivity of the briquettes.

The finished plates have a thickness of about $\frac{1}{40}$ inch across the web, and across the pockets of about $\frac{1}{10}$ inch.

The size of the plate varies with the capacity of the cell, having a greater or less number of pockets. The containing jar is also made up of nickel-plated steel sheets.

The initial voltage of discharge after recent charge is 1.5 volts.

The mean voltage of full discharge is 1.1 volts.

This cell has an energy capacity or weight efficiency of 14 watt-hours per pound of complete cell.

Charging and discharging rates are alike, that is to say, the cell may be charged at a normal rate in $3\frac{1}{2}$ hours; or it may be charged at a high rate in one hour, without apparent detriment beyond lowering the efficiency.

The current enters the cell at the positive plate and oxidizes the nickel compound to the peroxide state, and reduces the iron compound in the negative plate to spongy iron.

The electrolyte in this cell simply acts as a path for the passage of the oxidizing and reducing ions, and its own chemical composition does not change.

The cell is not appreciably influenced by changes in temperature. It is claimed that it may be fully discharged to the zero point of E. M. F. without injury, can be charged in reverse direction, then recharged to its original condition and suffer no loss in its storage capacity. The curve given in Fig. 9 shows a six hour discharge of an experimental cell, at a constant current of 42.5 amperes.

MANAGEMENT OF STORAGE BATTERIES.

In describing the handling of storage batteries, the various types of lead cells will be considered, as they constitute a very large majority of cells in commercial use.

The Battery Room. In the installation of a battery, the first point to be considered is its location. The room for this purpose should be dry, well ventilated and of a moderate temperature, otherwise the evaporation of the electrolyte will be excessive. The floor, walls and ceiling must be of some acid proof material, brick or tile being preferable, and the floor so made as to drain readily; an outlet being provided for the drainage system. If the room

should be an old one, and have a wooden floor, the floor should be coated with asphaltum paint, and lead trays placed below the batteries; any wood work or iron work in the room should be likewise treated.

The room should be sealed from the rest of the building, and located near the generating machinery and distribution switchboard, so that the copper cables may be low in cost. The windows in the battery room should be either of ground or painted glass, so that no direct rays of the sun may strike the cells, as the heat may crack the cells (glass) or increase the activity of the acid, which is not desirable.

In case the battery installation is in a cold climate, some device for keeping the electrolyte at a moderate temperature must be used. A simple plan is to suspend an incandescent lamp in the

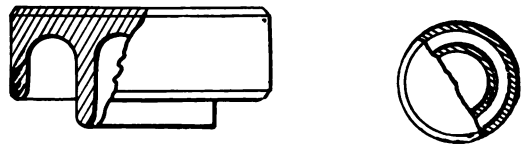


Fig. 10. Glass Insulator for Battery Support.

cell and have it connected to some automatic device which will put it out when the electrolyte is at the desired temperature or light it when the electrolyte is too cold.

Setting up the Cells. The battery is usually placed on the floor, or upon strong wooden shelves; Fig. 11 shows a form adapted to cells of medium size. Iron stands are sometimes used for large and heavy cells, but they must be protected from acid fumes and drip by several coats of an acid-proof paint. Wooden stands should be varnished, painted or soaked in paraffin for the same reason. It is important to have every cell accessible for inspection, cleaning and removal, it being desirable to reach both sides of the cell. There should also be sufficient head room between shelves so that the elements may be lifted out.

It is highly important that the cells be thoroughly insulated from each other, to avoid leakage of current. This is accomplished by standing each cell on four insulators of porcelain or glass of the design shown in Fig. 10. Porcelain is preferable to

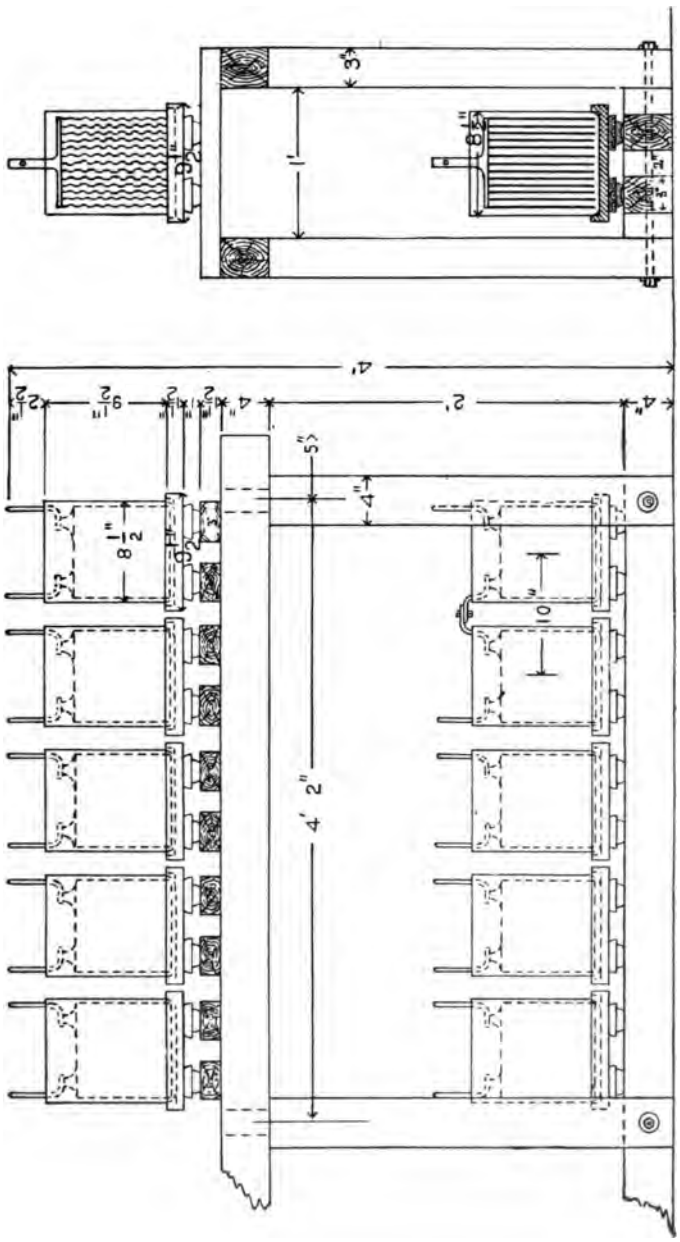


Fig. 11. Shelf Construction for Battery Support.

glass as the latter is sometimes pitted by the action of acid fumes.

Lead-lined tanks are usually set as follows: The floor is covered with a layer of glazed tile or brick; on this are placed two wooden stringers about 3 inches x 4 inches carefully painted with P & B or some acid-proof paint. On these are set four insulators held in place by wooden pegs which are kept in position by pouring melted sulphur around them. On top of these are placed the battery tray and battery as indicated in Fig. 11.

Oil insulators were at first used, but oil collects and holds dust, and as dust is likely to cause leakage they are no longer used.

For very large lead tank outfits a double system of the supporting construction shown in Fig. 11 is used, but with individual stringers for each cell.

Glass cells are often set on wooden trays, which are filled with sand to distribute the strains and absorb the drip. Saw-dust was also used, but it becomes carbonized by the acid drip, and as this is likely to cause leakage, it has been abandoned.

In connecting the cells, which are usually put in series, great care should be taken to join the positive terminal of one cell to the negative of the next and so on. The color of the plate is the best indication of its polarity, the positive plate being a light brown when discharged and a chocolate color when charged, while the negative varies from a dark slate to a light slate color.

It may be noted at this point that the nomenclature, concerning storage batteries, is different from that of primary cells. The positive plate in the former is the peroxide plate (brown) and is that one from which the current flows out in discharging, whereas that would be the negative plate of a primary battery.

The positive pole or terminal in a storage battery is an extension of the positive plate, and is connected to the positive terminal of the dynamo in charging; consequently there is much less cause for confusion of terms than there is in the primary cell.

It is well to test the polarity of each cell and of the circuit before making connections. This may be done with any form of pole tester, or by the positive expedient of dipping the two terminals in dilute sulphuric acid, the one from which the most bubbles arise being negative. The connections should be scraped clean and

screwed up very tight, being also coated with acid-proof paint to avoid corrosion. The most satisfactory way to connect up a cell is to weld or "burn" the positive terminal to the negative terminal of the next cell, though soldered connections are good.

This soldering is done as follows: Two strips of lead and the terminals to be connected are very carefully cleansed; the lead strips are then clamped to the terminals, a mold placed around the joints and molten lead poured into it.

The Electrolyte. Practice varies considerably as to the strength of solution to use. Chemically pure sulphuric acid is poured into water until its density becomes about 1.2, and then the mixture is allowed to cool before pouring it into the cells. The electrolyte should completely cover the plates. Cells for vehicle work use an electrolyte with density as high as 1.3. It is important to use perfectly pure acid and water, as impurities will cause local actions and ultimately destroy the plates.

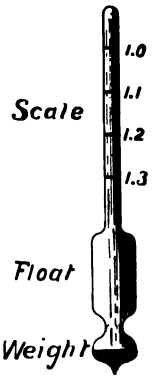


Fig. 12. The Hydrometer.

It is well to remember that water should never be poured into sulphuric acid, as it is likely to cause the liquid to be thrown out violently.

The advantage of a strong solution is its lower resistance; but it is likely to produce the very objectionable effect of "sulphating."

The density of the electrolyte falls immediately after filling a cell, since some of the acid is taken up by the plates; but it rises again in charging; for example from 1.17 to 1.2. It is convenient to keep a hydrometer in several cells to observe the density of the electrolyte, not only at the beginning, but as a permanent indicator of the amount of charge and general working conditions.

The hydrometer is an instrument for determining the specific gravity of a liquid, and consists of a weighted bulb and an upright glass rod, bearing a scale, the unit point being fixed by the distance to which it sinks in pure water at 4°C. Readings above this point are for solutions of lower specific gravity than water and those below it are for solutions of a higher specific gravity. For storage battery work the specific gravity of the electrolyte is

always between 1.1 and 1.3, hence we require only a certain portion of the scale as represented in Fig. 12.

Charging. The charging should begin immediately after a new cell is filled with the electrolyte, otherwise the plates are likely to become "sulphated." The first charge differs from subsequent regular charges in that it should be at a rate (lower than normal) that will not cause the temperature of the cell to reach 100°F, but in all other respects it is the same.

Indications of Amount of Charge in a Storage Battery:

1. The E. M. F. rises from 1.7 volts, which is the minimum value to which a lead cell should be discharged, to approximately 2.5 volts when fully charged, although this value may be made a trifle higher or lower, depending upon the rate of charge and temperature of cell. The rise is quite gradual, but more rapid near the beginning and end of the charge, as indicated in Fig. 13. When the cell is fully charged, the E. M. F. becomes constant and the curve approaches a horizontal line as shown. The charging should then be stopped as any more energy passed through the cell is simply wasted in producing gases. The external voltage is higher in charging than in discharging because of the internal resistance of the cell and resulting C R drop, which must be overcome in charging.

The measurements of voltage should always be made when the current is flowing either in charging or discharging.

The E. M. F. on open circuit has little practical significance.

2. *If a record is kept* of the exact number of ampere hours of charge and discharge, the actual amount of energy in the battery at any time is known, due allowance being made for leakage and other losses. For this purpose any integrating instrument such as the Thompson recording wattmeter may be used.

3. *The density of the electrolyte* gradually rises during the charging operation, Fig. 13; the density when charged being about .025 higher than when discharged. There is a lag in the change of the density of the electrolyte, the acid not being absorbed or given off at once by the plates, hence a little time should be allowed before taking any hydrometer reading as final.

4. *Bubbles of gas are given off* freely when the battery is fully charged, since the material of the plates is then no longer

able to take up the oxygen and hydrogen which tend to be set free by the electrolysis; these bubbles give the electrolyte the appearance of boiling, and often they are so fine that the liquid looks almost milky white, particularly in a cell which has not been very long in use.

5. *The color of the positive plates* varies from a light brown on active parts to a chocolate color when fully charged, and to nearly black when overcharged. The negatives vary from pale

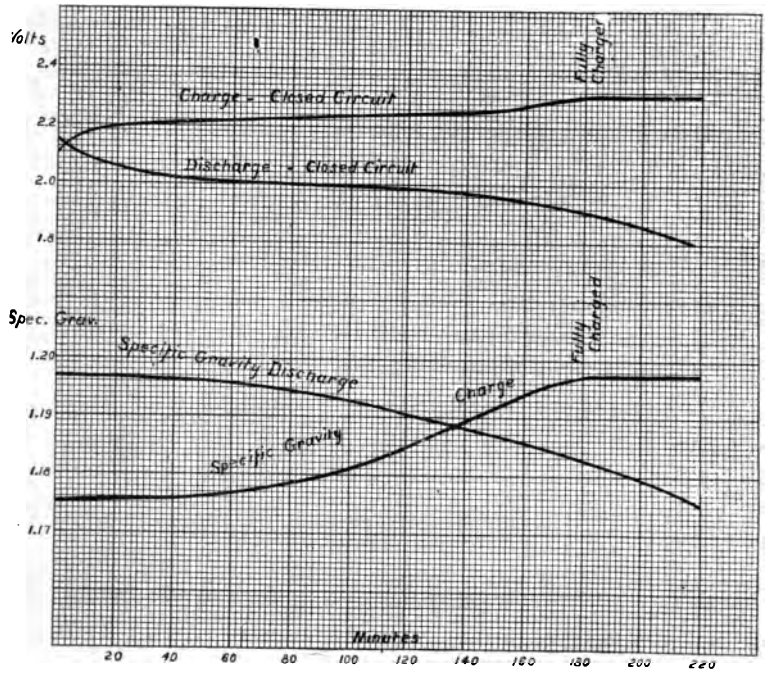


Fig. 13. Curves Showing Variations in Sp. Grav. and Voltage in a Storage Battery During Charge.

to dark slate color, but they always differ in color from the positives. This indication of the amount of charge is acquired by experience, but is quite definite after one becomes familiar with a particular battery.

6. *Cadmium Test.* The apparatus for making this test consists of a small piece of cadmium, say $\frac{5}{8}''$ x $\frac{5}{8}''$ x $\frac{1}{32}''$ mounted as in Fig. 14. A glass tube contains the conducting wire, wax being used to protect the soldered joint of copper and cadmium. Cad-

mium is used because it will give reliable readings of the E. M. F. of the positive and the negative plates, with respect to itself. In this way a relative condition of the battery and also of each plate can be determined.

With normal conditions of cell, when fully charged and in open circuit, the difference of potential between the positive and the cadmium piece is 2.5 volts or nearly so, and between the cadmium and the negative plate is zero or nearly so. In fact it is sufficient if the sum of the readings is about 2.5 volts.

To avoid false conclusions in making a cadmium test, hydrometer, temperature and charge data should be noted. The cadmium test is usually made at the center of the cell to get a uniform current distribution. This test gives readings the sum of which is less than 2.50 volts, when hydrometer tests, temperature and charge data show that the cell is not fully charged; but if the hydrometer, temperature, and other data show the charge to be completed, and the cadmium gives .1 volt or more below 2.5 volts, the defective plate is readily determined by individual cadmium readings. For example, suppose we have a cell in which all conditions tend to show full charge but the potential difference is low. A cadmium test is taken and whichever plate shows the falling off from normal reading, that plate is the defective one, and should be examined for some of the troubles that will be discussed later.

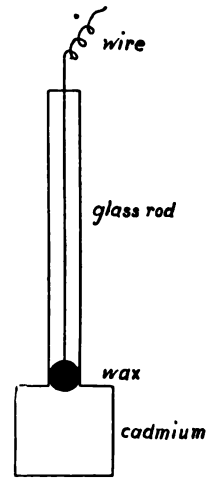


Fig. 14. The Cadmium Tester.

In some cases the cadmium reading with respect to both plates may approach zero; this is caused by a short circuit in the cell which should be found and removed immediately.

In practice it is advisable to have the cadmium wet before the test is made as the readings increase when cadmium is first placed in the electrolyte. The simplest way to accomplish this is to keep the cadmium tester in a beaker of distilled water when not in use. All foreign matter should be carefully removed from the cadmium as it might affect the results. If gas bubbles collect on the cadmium they should be taken off, as they tend to lower the readings.

The proper rate of charge depends upon the size and type of cell, and is usually specified by the manufacturer in each case, since it is merely an empirical fact, being determined by the construction of the plates.

The current for charging is ordinarily obtained from a direct current dynamo, but any other direct current source may be employed. The potential required for charging must exceed that of the battery, which, during the operation acts as a counter E. M F., the expression being $I = \frac{P - e}{R}$, in which I is the current, P the potential applied to battery terminals, e the counter E. M. F., and R the internal resistance of the cell. Usually P is 5 to 10 per

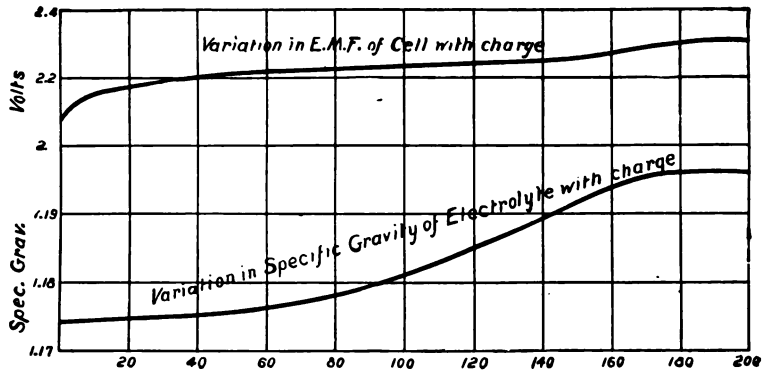


Fig. 15. Curve Showing Increase of E.M.F. in a Charging Cell.

cent greater than e, in order to cause the necessary charging current to flow through the resistance R of the cell.

In practice P is regulated until the required charging current I is obtained.

The above equation, put into form of $R = \frac{P - e}{I}$, enables the internal resistance R to be calculated, but as this varies considerably with the temperature, and with different states of charge, its exact value is not often considered.

Another form of the above equation, $e = P - IR$, shows that the true E. M. F. of the battery is less than the charging voltage by an amount equal to the product of the charging current and the internal resistance. Conversely, in discharging, the tota

E. M. F. of cell is greater than the difference of potential P between its terminals by the same amount, that is, $e = P - IR$. Hence it is necessary to know I and R, or to measure the voltage when the circuit is open (in which case $I = 0$), in order to find the real E. M. F. of cell. This applies to each individual cell as well as to the entire battery, and is important in determining the amount of charge or working condition of a particular cell.

If the charging voltage P be kept constant, it is evident from the above equtations that the current I will gradually decrease, since the C. E. M. F. or *e* of the cell steadily rises as shown in Fig. 15. This effect is counteracted somewhat by the fact that the internal resistance R also diminishes, owing to the density of the electrolyte increasing. This gradual reduction in the strength of the charging current is considered desirable by some authorities, since it enables the cell to take a greater charge than if the current were maintained at full strength. On the other hand, this diminishing charge makes it difficult to keep account of the exact number of ampere hours supplied to the cell; hence in ordinary commercial work it is considered simpler to charge with a constant current, and if it is desired to keep the cell temperature down, the current is decreased near the end of the charge. The charging operation may be continued until the battery is fully charged as shown by the indications already stated. Since most types of cells are not injured by a slight overcharging at a moderate rate it may even be carried a little beyond the charged point, as it tends to remove "sulphating." A considerable overcharge should be avoided as it causes excessive formation of gas bubbles in the active materials, is likely to heat the cell and even cause disintegration and buckling of the plates.

Discharging. A storage battery is in most cases discharged within a few hours after being charged, as, for example, in electric lighting, when the engine and dynamo are run during the day for charging the battery which supplies current to the lamps during the night. But a portable battery for feeding lamps might be required to retain its charge for several days. A certain loss of charge occurs in any battery, amounting to about 25 per cent in one week, but for one day or less it is quite small.

Even when the discharge occurs immediately, the average

voltage and the ampere-hours obtained are less than for the charge, as explained under "Efficiency." The loss referred to is additional, depending upon the time.

The operation of discharging is naturally the converse of charging, the changes which have been described as occurring in the latter take place also in the former, but in the reverse order. The normal rate of discharging is usually equal to that of charging, but may be somewhat greater. In some cases it is necessary to discharge at higher rates, but by so doing a percentage of the capacity in ampere-hours is sacrificed.

For example, a cell whose normal or eight-hour discharge rate is 100 amperes, can easily be discharged at 400 amperes for one hour, but only 50 per cent of the cell's capacity in ampere-hours is obtained at the latter rate.

An excessive discharge rate is injurious to most types of storage battery plates since it tends to disintegrate the plates, and abnormally heats the electrolyte, which hastens the disintegration; it is therefore advisable to protect the battery with fuses or an automatic circuit breaker.

A storage battery *should never be discharged completely*, as it is very likely to become "sulphated," or otherwise injured; and moreover the E. M. F. falls so rapidly towards the end of discharge that the current would be of no practical value. The limit of discharge is usually considered to be the point at which the E. M. F. drops to 1.75 volts, though when cells are used at the one-hour rate the limit of discharge is 1.6 volts.

The charge usually left in a storage battery is from 10 to 30 per cent of the total capacity, depending on the rate of discharge, but this involves no considerable loss of energy or efficiency, since it remains in the battery each time and the charging begins at that point.

The Efficiency of Storage Batteries. The efficiency of any apparatus is the ratio between what it gives out and that which it consumes. In a storage battery it is the ratio of the amount of discharge to what is put in to bring the battery back to its original condition after a discharge. While this seems extremely simple and definite there are several opportunities for confusion or quibble when applied to a secondary battery.

In the first place, the "ampere efficiency" or more properly the "ampere-hour efficiency" which is the ratio of current in ampere-hours drawn from the battery to current in ampere-hours put into the battery is quite different from the watt-hour efficiency. The latter is the real efficiency, since it considers the energy, and includes the voltage as well as the ampere-hours. Ampere efficiency may be scientifically interesting as showing the action of a battery; but it is not of much commercial importance. This is likely to be used either through ignorance or intention to give a false idea since the ampere efficiency is often 15 per cent higher than the watt efficiency.

Another difficulty with the ampere efficiency is the fact that it is possible to obtain an apparent efficiency of over 100 per cent from a storage battery. Since a certain amount (about 25 per cent) of charge is always left in the cell, it is possible to draw apparently more ampere-hours of current than were put in it, by simply discharging the cell more than usual.

This matter has been investigated by Ayrton, who states:

"If an E. P. S. accumulator be over and over again carried around the cycle of being charged up to 2.4 volts, and discharged down to 1.8 per cell, the charging and discharging currents being the maximum allowed by the makers, viz., .026 ampere per square inch of surface in charging, and .029 ampere per square inch in discharging, the working efficiency thus obtained may be 97 per cent for the ampere-hours, and 87 per cent for the watt-hours. If, on the contrary, the cell be constantly charged up before being tested, then for the first few charges and discharges between the above limits, and with the same current density in charging and discharging, even the energy efficiency may be as high as 93 per cent; whereas if the accumulator has been left for some weeks, then, although it was left charged, the energy efficiency for the first few charges and discharges will be as low as 70 per cent."

In general practice it has been found that the efficiency of storage battery plants, when in good condition, varies from 75 to 80 per cent. For instance, referring to the battery plant at the Edison Electric Company station in Boston, a series of tests made there shows the battery installation to have an efficiency of 75 per cent.

Depreciation of Accumulators. The depreciation is claimed to be as low as 5 per cent per annum; in fact both the Tudor and Chloride battery installations at the Boston Edison Company's plants are insured and kept in repairs by the makers for 4 per cent per annum of their total original cost. This figure is as low as the maintenance of the very best steam or electrical machinery. One of the largest electrical manufacturing companies in this country has in use a storage battery equipment which, for the past eight years, has not cost a cent in the way of repairs to, or renewals of, plates. On the other hand, the life of storage batteries in traction or automobile work has in some instances not exceeded six months, though it is claimed that these cells were only in an experimental stage. One must be somewhat guarded, however, in accepting low figures of this kind since from their nature the plates are very easily injured and difficult to repair. It would be very unwise for any one to purchase a battery without the makers' guarantee, to allow less than 10 per cent for its annual depreciation, and this does not include interest, taxes, or other fixed charges.

It has been the practice of several storage battery manufacturers to insure their battery equipments for 6 per cent per annum of their first total cost. This insurance is a maintenance contract calling for inspection and any repairs necessitated through normal use of cells.

TROUBLES AND REMEDIES.

The most serious troubles which occur in storage batteries are sulphating, buckling, disintegration and short circuiting of the plates. These can usually be avoided, or cured by proper treatment if they have not gone too far.

Sulphating. The normal chemical reaction which takes place in storage batteries is supposed to produce lead sulphate ($PbSO_4$) on both plates when they are discharged, their color being usually light brown and gray, due to presence of the PbO_2 still on the positive plate. But under certain circumstances a whitish scale forms on the plates, probably consisting of $Pb_2\,SO_5$. Plates thus coated are said to be "sulphated." This term is, therefore, somewhat ambiguous, since the formation of a certain

proportion of ordinary lead sulphate ($PbSO_4$) is perfectly legitimate, but the word has acquired a special significance in this connection.

A plate is inactive, and practically incapable of being charged, when it is covered with this white coating or sulphate, as it is a non-conductor.

The conditions under which this objectionable sulphating is likely to occur are as follows:

(*a.*) A storage battery may be overdischarged, that is, run below the limits of voltage specified, and left in that condition for several hours.

(*b.*) A storage battery may be left discharged for some time, even though the limits have not been exceeded.

(*c.*) The electrolyte may be too strong.

(*d.*) The electrolyte may be too hot (above 125°F).

(*e.*) A short circuit may cause "sulphating" because the cell becomes discharged (on open circuit) and when charging it receives only a low charge compared with the other cells of the series. A battery may become overdischarged or remain discharged a long time on account of leakage of current due to defective insulation of the cells or circuit, or the plates may become short-circuited by particles of the active or foreign substances falling between them.

Sulphating may be removed by carefully scraping the plates. The faulty cells should then be charged at a low rate (about one-half normal) for a long period. In this way, by fully charging and only partially discharging the cells for a number of times, the unhealthy sulphate is gradually eliminated. When the cells are only slightly sulphated, the latter treatment is sufficient without scraping; when the cells are very badly sulphated, the charge should be at about one-quarter the normal rate for three days.

Adding to the electrolyte a small quantity of sodium sulphate, or carbonate, which latter is immediately converted into sodium sulphate, tends to hasten the cure of sulphated plates by decomposing or dissolving the unhealthy sulphate. This is not often used in practice, as a cell must be emptied, thoroughly washed and fresh electrolyte added after the plates have been restored to their proper condition before the cell can be used to advantage.

Sulphating not only reduces the capacity of lead storage batteries, but also uses up the active material by forming a scale which falls off or has to be removed. It also produces the following trouble:

Buckling, or warping of a plate, is caused by uneven action on the two surfaces; for example, a patch of white sulphate on one side of a plate will prevent the action from taking place there, so that the expansion and contraction of the active material on the other side, which occurs in normal working, will cause the plate to buckle. This might be so serious that it would be impossible to straighten the plate without breaking or cracking it; but, if taken in time, it may be accomplished by placing the warped plate between boards, and subjecting it to pressure in a screw or lever press. Striking the plate is objectionable, because it cracks or loosens the active material; but, if it should be necessary to straighten a plate in this way, a wooden mallet should be used very carefully, with flat boards laid under and over the plate. Buckling may be caused by an excessive rate of charging or discharging, as well as by sulphating.

Disintegration. Some of the material may become loosened or entirely separated from the plates, as a result of various causes. The chief of these is sulphating, which forms scales or blisters that are likely to fall off, thus gradually reducing the amount of active material and the capacity of the cell. Buckling also tends to disintegrate the plates. Contraction and expansion of the active material may take place in normal working, and are increased by excessive rates or limits of charging and discharging. This constitutes another cause of disintegration, particularly in plates of the Faure type containing plugs or pellets of lead paste.

The fragments which fall from the plates not only involve a loss of material, but are also likely to extend across or gather between the plates, and cause a short circuit.

The positive plates are far more susceptible to and injured by these troubles than the negatives. The former are also more expensive to make, therefore it is to them that special attention should be directed in the management of storage batteries.

Short Circuiting of cell may be caused by conditions previously stated and also by the collection of sediment at the bottom

of the containing cell. The short circuiting caused by the dropping in of foreign matter, or the bridging of the active materials, is prevented by the use of glass, rubber or wooden separators.

The short circuiting of plates by the formation of sediment is prevented, or the chances of it are decreased by raising the plates so that they clear the bottom of the containing cell. In small batteries this clearance is about an inch, in large cells it is considerable, being about 6 inches, and on account of the weight of large sized plates they are supported at the bottom by glass frames running lengthwise through the cell, as shown in Fig. 16.

This sediment should be watched carefully and when it reaches a depth of 1 inch or more at the center of the cells, it should be removed. The usual method is to take out the plates, syphon the electrolyte off carefully, and then flush out the tanks until all the sediment is removed. If syphoning cannot be resorted to, due to absence of drop, a pump may be used, either of glass or of the bronze rotary type.

Troubles from Acid Spray. An accumulator gives off occasional bubbles of gas at almost any time or condition; but when nearly charged, the evolution becomes more rapid. These bubbles, as they break at the surface, throw minute particles of acid into the air, forming a fine spray which floats about. This spray not only corrodes the metallic connections and fittings in the battery room, but is also very irritating to the throat and lungs, causing an extremely disagreeable cough.

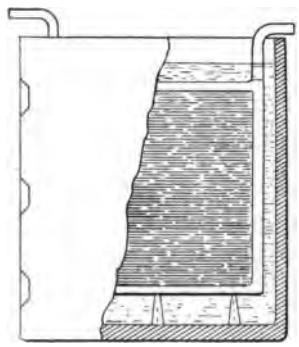


Fig. 16. Glass Frame Support Used to Prevent Short Circuiting by Sediment.

Glass covers are sometimes placed over cells to prevent the escape of fumes, but this is not advisable as the glass becomes moist and will collect dust, thus forming a conducting surface over the cell.

Attempts have been made to do away with this spraying by placing an oil film (thin layer of oil) over the electrolyte, but this has the objection of interfering with hydrometers; in addition it sticks to the surface of the plates when they are removed, and interferes with their conductivity on replacing them.

Another plan consists of spreading a layer of finely granulated cork over the surface of the liquid, but while this does not interfere with the hydrometer, it makes the cell look dirty.

The general practice is to depend almost entirely upon ventilation to get rid of the acid fumes, in fact, even forced ventilation is used. A blower forces fresh air into the room, which is provided with a free exhaust.

In connecting up the cells, it is advisable to use lead-covered copper cables, as this covering protects the copper, and prevents the formation and the dropping of copper salts into the cell.

The Purity of the Electrolyte is very important, and great care should be taken to insure it. The electrolyte may have nitric acid present when "formed" (Planté) plates are used, and some chlorine, when "Chloride" negatives are used. In addition, iron may be present due to the water or acid; if the sulphuric acid is made from iron pyrites; it may also be present, owing to the corrosion of iron fittings near the cells, some of the scale falling into the electrolyte. Similarly some of the copper salt formed from the connections by this corrosive action may fall into the cell. Mercury may also be present due to the breakage of hydrometers or thermometers.

Other foreign substance might be present, but those named are the most harmful.

Nitric acid, even in exceedingly small quantities, will cause disintegration of plates, as the supporting material is destroyed.

Chlorine has a similar effect.

Iron, mercury and copper produce local action, and thus decrease the efficiency and ultimately the life of the cells.

The electrolyte should be tested about once a week for these impurities, and if any of them are present, it should be drawn off and renewed. If nitric acid is present, it is even advisable to flush the cell with pure water.

TESTS.

1. **Test for Chlorine.** To a sample of electrolyte in a test tube, add a few drops of silver nitrate solution; if a curdy white precipitate forms, an excess of ammonia is added, and if this dissolves the precipitate, chlorine is present in some form.

2. **Test for Iron.** Iron may appear in one of two forms, namely, ferrous or ferric salts. A small sample is taken and some concentrated hydrochloric acid added and then some potassium ferric cyanide; if a heavy blue precipitate forms, ferrous iron is present; if in very minute quantities, a deep blue green discoloration results.

3. **Test for Ferric Salts.** To a sample add some ammonium thio-sulphate; if a blood red solution or precipitate is the result, ferric iron salts are present.

4. **Test for Copper.** To a sample of electrolyte an excess of ammonium hydrate is added; if a rich blue solution is the result, copper is present. It is advisable to check the test by taking another sample and adding some potassium hydrate to it; if a blue precipitate is found which turns black upon boiling, it is additional proof of the presence of copper.

5. **Nitric Acid** being injurious even in very small quantities, it is advisable to make the following test, which is very sensitive. Some diphenylamine in concentrated sulphuric acid is added to the sample; if a deep blue color is the result, nitrates or nitrites are present.

6. **Test for Mercury.** Mercury may be present in two forms, mercurous or mercuric compounds. The *mercurous* compounds give a black precipitate with lime water, and a greenish precipitate with potassium iodide.

The *mercuric* compounds give a yellow precipitate with lime water, and a red or scarlet precipitate with potassium iodide.

On account of possible difficulties with these various impurities the following is recommended:

1. Test every carboy of sulphuric acid before using.

2. Concentrated sulphuric acid should not be kept around, as it may be used by mistake, which would ruin the plates.

3. Only distilled water from carboys should be used and not from barrels, as it may be contaminated from the organic material of the barrels.

4. Water from the city mains is never to be used unless the amount of iron it contains is very small.

5. When testing with hydrometer for acid strength (specific gravity) the battery should be fully charged and tests always made at the same temperature.

Putting the Battery out of Commission. If, for any reason, the battery is to be but occasionally used, or the discharge is to be at a very low rate, a weekly freshening charge to full capacity at normal rate should be given.

It frequently happens in practice that a storage battery equipment is put out of commission for a lengthy period, (for instance, in most summer or winter resorts the battery may be used for one half of the year only). In such cases the procedure is as follows: First give the battery a complete charge at normal rate, then syphon off the electrolyte into carefully cleaned carboys (as it may be used again), and as each cell is emptied, immediately refill it with pure water. When the acid has been drawn from all cells and replaced with water, begin discharging the battery and continue until the voltage falls to or below one volt per cell at normal load (rate); when this point has been reached the water should be drawn off. In this condition the battery may stand without further attention until it is to be again put into service, and to do this proceed in the same manner as when the battery was originally put into use.

If during the discharge, when the water has replaced the electrolyte, the battery shows a tendency to get hot (100°F,) add colder water.

Commercial Application. The function of a storage battery is to receive electrical energy at one time or place, and to give it out at some other time or place.

The principal uses are the following:

1. To furnish portable electrical apparatus with power.

2. To make up for fluctuations, and thus steady the voltage and current.

3. To furnish energy during certain hours of the day or night, and thus enable the generating machinery to be stopped.

4. To aid the generating plant in carrying the maximum load (peak) which usually exists for only an hour or two.

5. To make the load on engines or prime movers more uniform, by charging the battery when the load is light.

6. To transform from a higher to a lower potential by charging the cells in series, and discharging them in parallel, or vice-versa.

7. To subdivide the voltage, and enable a three or a five wire system to be operated from a single generator.

Fig. 17. Gould Portable Storage Battery.

8. To supply current from local centers or substations.

9. To supply current to electrically driven vehicles.

10. As sources of current in telephone and telegraph systems.

11. For car lighting purposes.

12. As sources of constant potential and current in electrical laboratories.

Portable Storage Batteries. The storage battery is practically the only means of supply for portable electric lamps, or those not connected to a dynamo even when they are not portable. The primary battery is expensive and troublesome to operate; and has never been commercially successful for electric lighting or power, except where only a very small amount is required. Nor is there any other satisfactory primary source of electrical energy except the dynamo driven by mechanical power. It is therefore practically essential to adopt storage batteries wherever portable electric motors, lamps, etc., are used.

The various manufacturers furnish portable forms of storage batteries: for example, the Gould Storage Battery Company's portable battery (Fig. 17) is arranged in a case made as a hard rubber jar, lead-lined box or glazed earthenware jar, over which is placed a rubber gasket, and then a wooden cover clamped in place by U shaped straps, passing around the containing vessel. For ventilation in charging, the cover has threaded holes which, when the battery is in use, are closed with hard rubber stoppers. The usual number of cells in a case is from one to five, although they are made up in larger numbers if desired. The batteries are rated at 2 volts per cell.

A serious objection to portable storage batteries is their great weight. For example, a standard size weighing 100 lbs. yields 5 amperes at ten volts, or fifty watts for ten hours: just enough to feed a 16 C. P. lamp. The total discharge is 500 watts-hours or two thirds of one H. P.-hour. The special forms of battery used in automobiles give about twice this output for the same weight.

This weight is almost prohibitive to portability except for automobiles, railway train lighting and special purposes.

Portable batteries, for example, are used for feeding small motors, lamps etc. for medical or dental purposes, in which cases their weight is not a serious difficulty in view of the importance

of the work, and the small amount of energy required. Another special field for very small batteries is the theatrical application for which they are carried by the performers. Storage batteries are also being extensively used as source of power to drive small fan and kinetoscope motors.

Storage Batteries for Preventing Fluctuations due to unsteadiness in the driving-power or in the load, as with elevators, are often applied successfully. A dynamo driven by a gas-engine, for example, may vary periodically in speed because of the explosive action of the gas in the cylinder; and a battery connected in parallel with the dynamo will have the effect of steadying the voltage. A storage battery is generally installed in connection with a small gas or steam engine lighting plant to enable the engine to be stopped for a considerable portion of the time, and thus save labor and attention, in which case the battery may also act to prevent fluctuations. A windmill electric-lighting plant must have an accumulator or some other means of storing energy, not only to eliminate fluctuations in speed which are continually occurring, but also to bridge over the considerable periods of calm weather.

To Furnish Energy During Certain Portions of the Day or Night. In almost every electric-lighting plant, there are long periods during the day and late at night when the number of lamps lighted is so small that it may not pay to run the generating machinery.

For example, Fig. 18 is a load diagram showing the weekly output of the electric plant of the Astor Building in New York City. The generator plant runs from 3 A.M. to 8 P.M. each day, the battery being charged from 3 A.M. to 11 A.M.; and when the generating plant is shut down at 8 P.M. the battery carries the entire load from then until 3 A.M., when the plant is started up again. Saturday nights the plant is shut down at eight o'clock, and the battery furnishes all the power required from then until Monday morning at 3. This enables the plant to be operated by two gangs or shifts; practically no labor being required for the remaining seven hours as the battery carries the load, and the machinery is stopped entirely all day Sunday, giving a stretch of thirty-one hours once a week and seven hours each

night for cleaning and repairs. In a hotel, residence or on board a yacht, it may be desirable to stop the machinery and avoid the vibration and noise during the night.

Storage Batteries to Aid in Carrying the Maximum Load. Assume in the case of the load diagram shown in Fig. 19, that the generating machinery is capable of supplying 8,000 kilowatts and that a storage battery is used to furnish the remaining 3,600 kilowatts at the time of maximum load, that is, the "peak" of the load diagram. This simply means that batteries are substituted for a certain portion of the machinery plant, and the question is whether or not the substitution is of any advantage.

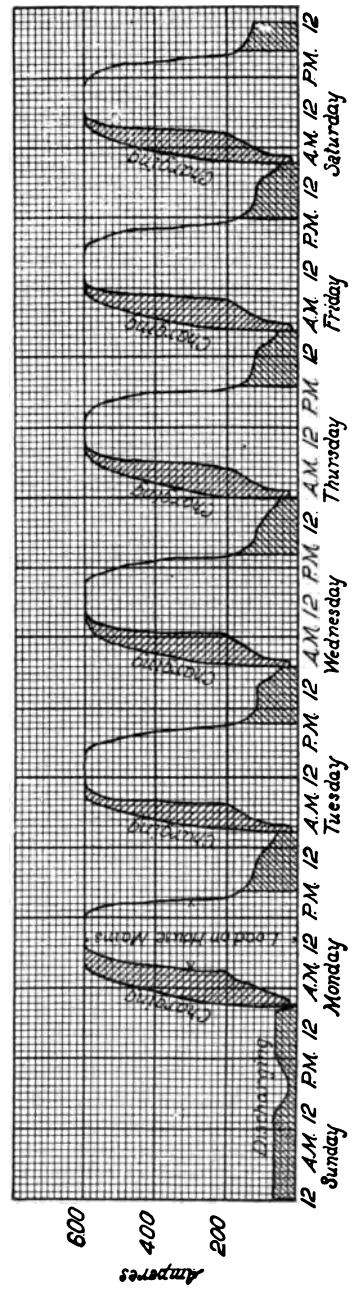

12 A.M. 12 P.M. 12 A.M. 12 P.M. 12 A.M. 12 P.M. 12 A.M. 12 P.M. 12 A.M. 12 P.M. 12 A.M. 12 P.M. 12
Sunday Monday Tuesday Wednesday Thursday Friday Saturday
Discharging
Charging
Load on Power Mains
600
400
200
Amperes

Fig. 18. Load Curve of Astor Court Building.

The first cost of a battery for a given rate of output depends simply upon the time of discharge. Batteries usually have a normal period of discharge of about 8 hours, at which rate the price of accumulators to furnish a given number of watts would be 3 to 5 times as great as that of the equivalent boilers, engines and dynamos combined, but if the time of discharge is reduced to about 2 or 3 hours, the costs are about equal and with a still higher rate the cost of batteries would be less.

As a matter of fact, the storage battery secures other advantages so that the total gain may be very important. For example, there is a reserve supply in case of accident and the load may be made more uniform as will now be explained.

Storage Batteries to Maintain Uniform Load on Engines. Steam engines are very inefficient at light loads, and this fact often causes serious losses especially in electric-lighting plants. Judicious selection of the number and sizes of the engines enable them to be worked in most cases at a considerable fraction of their full capacity nearly all of the time. Nevertheless, the storage battery gives greater flexibility to the plant, and renders it easy to increase the economy of the engines by making their loads

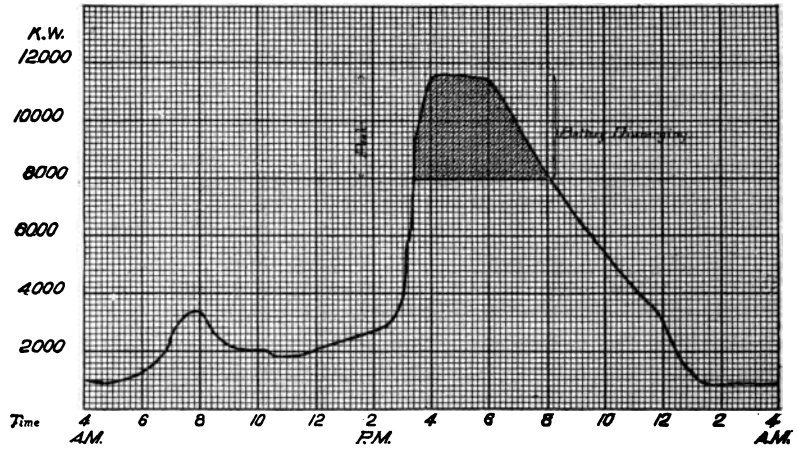


Fig. 19. Load Curve Showing "Peak" of Load Carried by Storage Battery.

still more uniform, and nearer to their full capacities while they are running. The engines can be made to have a uniform full load, the battery being charged when the external load is light, and the battery taking the peak of the load when it is heavy.

Storage Batteries Used as Transformers. If the cells of a battery are arranged in series while being charged, and in parallel for discharging, a high voltage will be required for charging, and a low voltage will be given out. The amounts of energy measured in watt hours are the same, less the loss of about 25 per cent which always occurs in accumulators; the result is similar to that obtained by an alternating current transformer or motor-dynamo

but is less efficient. As an example the equipment used at the Brooklyn Navy Yard may be mentioned. It consists of about 250 small cells connected up in series parallel of 5 sets of 50 cells each and charged on a 110 volt circuit. When discharged they are connected up all in series and give about 500 volts but with very small current. This equipment is used to furnish 500 volts for the "insulation test" of cables and therefore requires little or no current.

Storage Batteries Used for Subdividing Voltage. The most important practical case is that in which a dynamo of 220 volts charges a battery of corresponding potential, a three wire system being supplied from the battery, the neutral wire of which

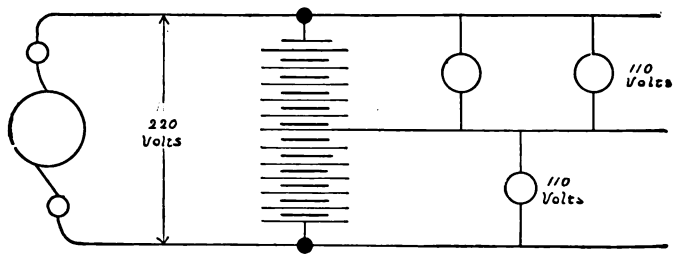


Fig. 20. Battery used to Sub-divide Voltage.

is connected to the middle point of the battery as represented in Fig. 20. This arrangement avoids the necessity of running two dynamos, and allows the battery to be placed in a sub-station near the district to be supplied, so that it is only necessary to run two conductors to that point instead of three. The same principle may be applied to the five-wire system.

The Hartford Electric Light Company was one of the first in this country to introduce the modern method of high tension transmission, with low-tension 3 wire distribution.

The auxiliary battery used in connection with this equipment consists of 130 Chloride Accumulators (65 on a side) each cell containing 31 negatives and 30 positive plates, each $15\frac{1}{2}''$ x $31''$, placed in lead lined tanks measuring $58\frac{1}{4}$ x $21\frac{1}{2}$ x $43\frac{7}{8}$ inches. Fig. 21 is a diagram showing the general plan of the system. The power is transmitted 10.8 miles from the Farmington River

Power Station to the Pearl Street Station, in Hartford, by means of step-up transformers, a ten thousand volt transmission line, and step-down transformers for distribution. From Pearl Street Station to State Street, a distance of three thousand feet, the current is transmitted at twenty-four hundred volts, at which latter point, by means of step-down transformers and rotary converter, the storage battery is charged and the current distributed over a low tension three wire system.

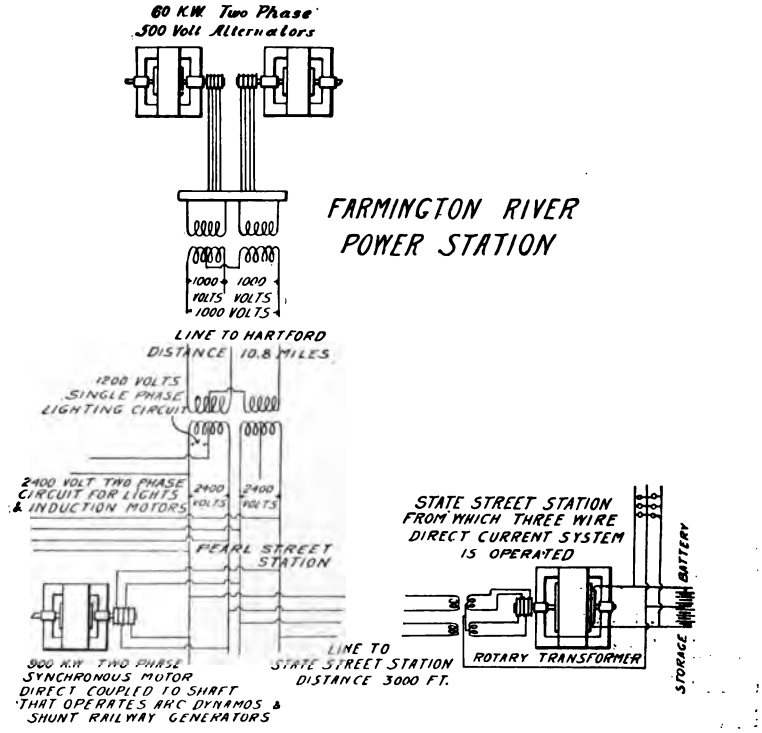


Fig. 21. Plan of the Farmington River — Hartford Distribution System.

Storage Battery for Sub-Stations. The plan of installing battery plants at local centers, which are charged from the main station, enables some of the conductors to be saved in a three (or five) wire system, as already stated. It also makes it possible to reduce the size of these conductors, because the current which flows over them can be kept practically constant, so that it is not necessary to have them large enough to carry the maximum cur-

rent consumed by the lamps, etc. which may be several times its average value. The generating machinery has the same steady load as if the battery were located near it.

The batteries at the various sub-stations may be connected and charged in series or in parallel. The former plan would require far less copper in the conductors since the voltage is multiplied by the number of batteries in series, and the current is the same as for a single battery. On the other hand, this great difference of potential would exist between the first and the last batteries of the series and if either of these became grounded, any person connected to the earth and touching a wire supplied by the other battery would receive a shock due to the total voltage.

An excellent example of the storage battery sub-station is the Bowling Green Plant of the New York Edison Company the description of which is as follows: The Bowling Green Station furnishes an auxiliary supply of current directly from the battery, enabling the feeders, extended as tie feeders into the Bowling Green building, to be used as distributing feeders to the system from both the Duane Street and Bowling Green Stations. While acting as an auxiliary supply to the general system, the battery also takes care of the distribution of current to the extensive installation in the Bowling Green Building itself. The supply of current to charge the battery is taken from the Duane Street Station, about a mile distant, over four tie feeders equipped with controllable disconnective switch boxes on the Bowker-Van Vleck system. This enables them to be used as tie feeders by disconnecting them from the general system during the hours of light load, and as distributing-feeders during the hours of maximum load, when they feed current into the system from each end. A considerable saving is thus effected in the investment because costly feeders are not required to supply the maximum load to a distant part of the system.

This installation of an auxiliary source of current supply in the lower district makes it possible to shut down the generators in the Duane Street Station during the hours of minimum load, the supply of current to the district below 8th Street being derived from the battery plants at Bowling Green and 12th Street Stations, supplemented, if desired, by the supply of current from

the 26th Street Station over the tie lines to 12th Street Station, whence the current is distributed through boosters raising it to the required potential, over the tie feeders to the Duane Street Station switch board. The battery and operating rooms of the Bowling Green Station are located in the sub-basement of the Bowling Green Office Building. Vitrified hollow tile for conducting the feeder cables are laid under the battery room floor, which consists of glazed white tile. Drains to carry off the water or acid run in the aisles between the cells and lead to small cesspools which discharge into a lead drain pipe.

The battery consists of 150 Chloride cells, seventy-five in series on each side of the three wire system. The cells consist of wooden tanks, 40¾ by 21½ by 30½ inches, treated with an acid proof paint and lead lined, each containing 14 positive and 15 negative plates 15½ inches wide by 31 inches high. Each tank is supported on four petticoat porcelain insulators resting upon 6-inch glazed tiles.

The plates are suspended in the tanks by shoulders resting upon sheets of heavy glass, which stand upon lead saddles in the bottoms of the tanks. The cells are connected by welding the plate terminals to lead bus bars, no mechanical connections being used.

Twenty of the end cells on each side of the system are used for regulating; being separately connected to contact points on the regulating switches, which carry movable contacts operated by a screw. The potential is raised or lowered by cutting in or cutting out the regulating cells. Two regulating switches are connected in multiple on the positive and two on the negative sides to permit of discharge at two potentials, or to enable the battery to be charged and discharged simultaneously. The conductors between each series of cells, and between the regulating cells and the regulating switches, consist of copper bars 3 inches wide by ½ inch thick. These bars are supported on porcelain insulators resting in hangers.

The connections of this equipment are shown in Fig. 22.

The capacities of the battery at various rates of discharge are:

2000 amperes per side for 1 hour.
1000 amperes per side for 3 hours.
400 amperes per side for 10 hours.

Provision has been made in the battery-room for the installation of a duplicate battery, which can be placed over the present plant. The booster is used to raise the voltage from that of the system to that required for charging the battery. The booster can be used also to raise the voltage of discharge for feeding some distant point of the system at a higher potential than would be normally required. The machine consists of one positive and one negative dynamo at each end of a common shaft driven by two

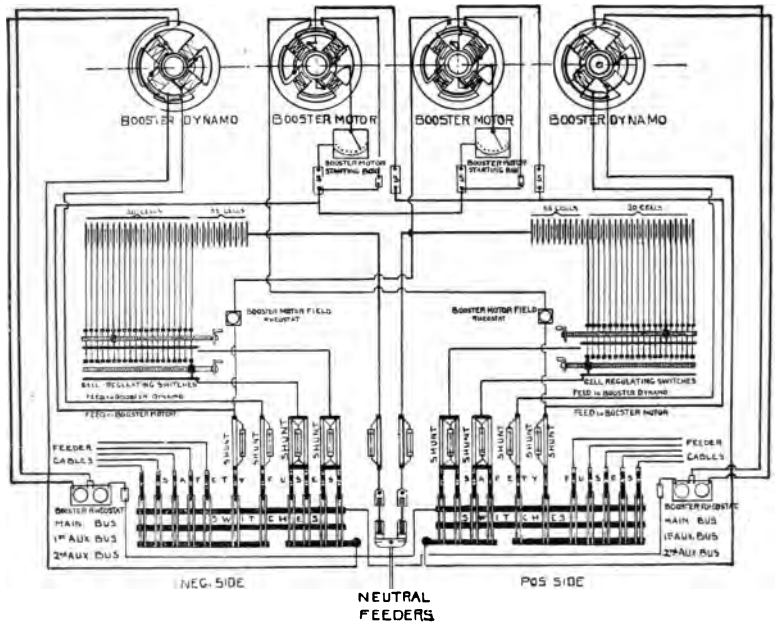


Fig. 22. Connections of the Bowling Green Storage Battery Sub-station.

motors. Each dynamo has a capacity of 1200 amperes and a range of pressure up to 60 volts.

Storage Batteries Used for Two or More of the Above-named Purposes. Each of the different uses has been considered separately to avoid confusion, but in most cases the storage battery is adopted in order to secure several advantages. By thus combining different applications the plant is rendered not only more economical, but also more flexible. For example, the battery may be utilized to help out the generating machinery at times of heavy load, or when the latter is partially or wholly dis-

abled. It often happens that it is difficult to produce or maintain sufficient steam-pressure, owing to poor draft or other conditions, in which event a battery enables the boilers to be temporarily relieved of some or all of the drain upon them while the pressure is being raised to the proper point. It may also be necessary or desirable to shut down the machinery or a portion of it, temporarily, in order to make some repair or adjustment. It is also possible to feed some of the circuits from the battery while the others may be supplied at a higher or lower voltage by the machinery. In these and many other ways the storage battery may be a convenient adjunct to an electrical system. The fact that it is so radically different from the machinery in its nature and action makes it very unlikely that the entire plant will be crippled at any one time, since the two sources of current are not exposed to the same dangers. An accident to the steam-piping, for instance, might shut down all the machinery, but probably it would not affect the battery; and, vice-versa, an accident to the latter is not likely to extend to the former.

As an example of this application of the storage battery to several purposes, the following case may be cited:

The installation of storage batteries at the power house of the Woronoco Street Railway Company, in Westfield, Mass., presents features of special interest. After considering various methods of increasing the power-house capacity, rendered necessary by the construction of an extension of the line, it was decided that the storage battery offered the greatest advantages.

The station equipment consists of two 75-KW. multipolar generators belted to two 120 H.P. high-speed, simple, non-condensing engines, steam being furnished by two 90 H.P. return tubular boilers.

The battery consists of 264 cells of the "Chloride Accumulator," Type F–11, in glass jars of Type F–13, permitting an increase of 20 per cent by the addition of one pair of plates in each cell, and is installed in a small brick extension to the power house. The cells are located in one tier, each cell being supported on a sand tray resting on four glass insulators. The foundation for each row of cells consists of two stringers of wood suitably braced and supported on brick piers. This battery was not in-

stalled as a voltage regulator, the feeder system being so designed that the drop on the line is only a small amount.

By means of the battery the load on the machinery is reduced within the capacity of one unit, leaving the second one as a reserve in case of an accident or an unusually heavy load. Without the battery both machines would be needed nearly all the time.

The economy of operation, due to using one unit instead of two, is clearly shown by the following station records.

	Date, 1899.	Lbs. coal.	Output kw.-hrs.	Lbs. coal. per kw.-hr.
With battery	Oct. 25-27	16,250	3,032	5.36
Without battery	Oct. 28	6,250	981	6.37

This shows an increase in the coal consumption of 19 per cent. on the day when the operation of the battery was discontinued. The plant is also noteworthy from the fact that the station attendance is reduced to one man per shift, the engineer doing his own firing. This arrangement could not have been continued under the conditions of increased load, had it not been for the improved regulation and reduction of coal handling, and especially the increased reliability of operation secured by the battery.

On several occasions the battery has been called upon to carry the entire load of the system for an hour or so, during a temporary shut-down of the rest of the plant, as well as early in the morning or late at night, when only one or two cars are in operation.

Storage Batteries for Propelling Vehicles and Boats. The storage battery is usually about 35 per cent of the total weight in the modern electric automobile, and even with this great proportion, the distance run on one charge is seldom more than from 20 to 40 miles at a speed of about ten miles per hour, and that only on comparatively smooth roads. The ordinary battery equipment consists of about 44 cells of 108 ampere-hours capacity with an average discharge voltage of about 1.9.

In cities or where the roads are good, with charging stations close at hand, the electric automobile is superior to the gasoline types, on account of the absence of explosive vapors, with the accompanying odor and noise. But for general touring they are not as handy on account of the limited capacity of the battery.

The application of the storage battery to the street car, while presenting such great advantages as the entire absence of poles and overhead wires, has not been a commercial success, mainly on account of the mechanical weakness of the plates, which are not able to stand the jolting and jarring or the rush of current due to frequent starts and stops. Another objectionable feature and one that caused trouble in New York City on the 34th Street crosstown line, is the escape of acid fumes into the car, producing throat irritations and coughs among the passengers.

The storage battery has been comparatively successful as a source of power in submarine boats, being charged while the vessel is on the surface, and discharged to run electric motors and lights when the vessel is manœuvering under the surface.

Storage Batteries in Telephone and Telegraph Systems. Since the adoption of the central battery systems by telephone companies, the use of the storage battery for this purpose has become very common, its advantages over the primary cell being as follows: Lower first cost, smaller space required (about $\frac{1}{4}$ of that occupied by an equivalent primary battery), greater constancy of E. M. F. and lower internal resistance, absence of the annoying "creeping salts," and rapidity of recharge. The cost of storage battery maintenance is about $\frac{1}{8}$ that of the primary cell.

In telephone work, the battery is installed in the district station, and charged when the line is not in use, from either a street connection or a generator in the station. When the line is in use for conversation, the charging current is automatically cut off, and the battery alone switched into service.

The storage battery in telephone work has become so important that the following description of a typical installation is given.

In the Filbert Street Exchange of the Philadelphia Bell Telephone Company there are two generating units, forming a duplicate plant, each consisting of one engine, directly connected to a 30 K. W., 110 volt dynamo. These machines are run on alternate days and are used for lighting the building and for furnishing power at 110 volts to various motor generators. The latter comprise two 1.5 K. W. machines for charging a 20-volt battery, one 1.5 K. W. machine for charging an 8-volt battery; one 500-watt machine for charging a 4-volt battery, and two $\frac{1}{4}$ H. P. 75-volt

alternating current motor-dynamos for ringing call bells. Only one machine is installed for the 8-volt battery and one for the 4-volt battery. Both batteries are in duplicate. To avoid a possible break down, a rheostat is furnished, so that the batteries of lower voltage can be charged from batteries or motor-generators of higher voltage. All machines are protected by automatic cut-outs.

The 20-volt battery consists of ten "Chloride Accumulators" having a capacity of about 1,000 ampere-hours, which furnish all the current needed by the subscribers for talking and for calling up the central office. The 8-volt batteries, in duplicate, consist of four cells each having a capacity of 2,400 ampere-hours. This battery furnishes current for the "disconnect" signals on the operator's cords, and for the relays which cut out the subscriber's lamp signal when the operator answers his call, by plugging into the jack corresponding to the lamp signal.

Half the drop in potential of the 8-volt battery is in the 4-volt lamp, and the other half in the cut-out relay. This battery is in duplicate, so that one can be charged while the other is being discharged. This avoids danger of burning out the lamps, as the voltage of the battery is raised from 8 to 10 volts during charging.

Each of the duplicate 4-volt batteries comprises six 13-cells arranged in two sets. One of these sets consists of four cells, two in series, two in multiple; the other of two cells. The two extra cells are needed on one of the batteries to supply current for the operator's transmitters. The latter is arranged to furnish a current of four volts or two volts as desired. The 4-volt battery also furnishes all current for the lamp signals which light when a subscriber takes his telephone off the hook. This lamp is put out when the operator answers the call. This battery also is made in duplicate, one being charged while the other is discharged, to avoid burning out the lamp from the higher voltage during charge.

Storage Batteries for Train Illumination. When cars are lighted by oil or gas lamps, these, owing to their size, and the heat produced by them, can be installed only in certain places, so that the distribution of light is not general, besides which, the heat and odor given off by the lamps are objectionable. The in-

flammable character of the illuminants involves great danger of explosion or fire in case of a train wreck. The absence of these disagreeable and dangerous features in electric lighting, is what has made its application so desirable in traction work.

Several methods of electric illumination have been tried on railroad trains. In one of the simplest of these a small dynamo, on the locomotive truck, or one perched above the boiler, is driven by a small steam turbine. While this is an economical method, it has the objection, that when the locomotive is uncoupled, the cars must be illuminated by some other means.

For this reason, the storage battery system of supply has been adopted. A description of one of tne most successful meth-

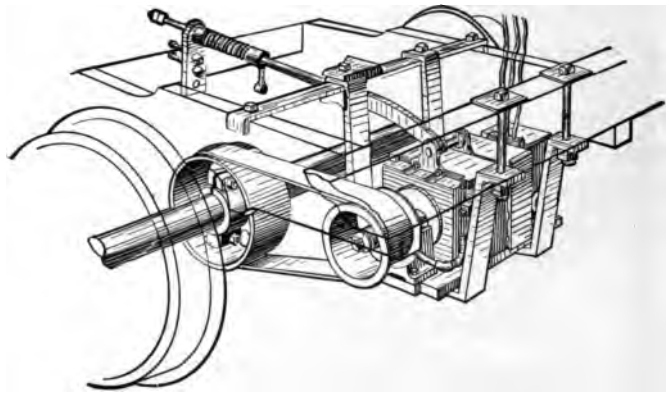


Fig. 23. Method of Suspension Used by the "Axle Light" System.

ods is as follows: The "Axle Light" System, as its name implies, derives the motive power for its dynamo from the car axle. The mechanism is suspended from the bottom of the car, and is completely encased, so as to be dust and water proof. It comprises a small dynamo driven from a pulley on the axle of the car by means of a friction coupling.

The dynamo and driving mechanism are shown in Fig. 23. The former generates from 32-40 volts, depending upon the speed of the train provided that it exceeds 15 miles per hour, the dynamo being then automatically connected to the battery and lamp circuit. An automatic device rectifies the direction of current, so that even though the direction of rotation is reversed, the battery

is always charged in the proper direction. A variable resistance in series with the field coils is automatically adjusted by a small motor, so that even at high speed the normal limit of voltage is not exceeded.

The lamps are 16 C. P. at 30 volts, the filaments being short and heavy so that they are not injured by vibration.

After the storage battery has been charged, it acts in parallel with the dynamo and avoids fluctuations in voltage. When the car stops, the dynamo is automatically cut out and the full supply of current is furnished by the battery, which is large enough for a ten-hour supply at full load.

Storage Batteries for Electrical Laboratories. The great advantage of this source of power in electrical laboratories, is the fact that any variation in the voltage is very gradual, and by the simple regulation of a rheostat in series with the battery, the operator can keep his voltage and current absolutely constant, while a test or calibration is being made. When a large current is wanted, as in the case of ammeter calibration, the cells may be connected in parallel, and discharged through a low resistance, thus cutting down the energy required for the test. A storage battery may also be used to step up the voltage, the cells being connected in parallel groups for charging and in series for discharging.

Connection and Regulation of Storage Batteries. The complete control of a battery in an electric-lighting plant requires provision to be made for feeding the lamps, etc., from either the dynamo or battery separately, or from the two working in parallel; and it should be possible to charge the battery at the same time that lamps are being supplied. To accomplish these results requires three switches,— one to connect the battery to the dynamo, one to connect the lamps to the dynamo and one to connect the lamps to the battery. In some plants the second switch is omitted, because the lamps are always fed by the battery alone, the latter being charged during the day, when no lamps are in use. However, it would seem desirable to have all three switches in every plant in order to be able, at least, to supply lamps and charge the battery at any time. In the battery circuit there should be an amperemeter having a scale on both sides of zero, so that it shows whether the battery is being charged or discharged, as well as the

value of the current. Another amperemeter is required in the circuit between the dynamo and the battery, to show the direction and amount of current. A third amperemeter is desirable in the lamp circuit, to show the total current supplied to the lamps; but it need only indicate on one side of zero, since the current there always flows in the same direction. A voltmeter is required with

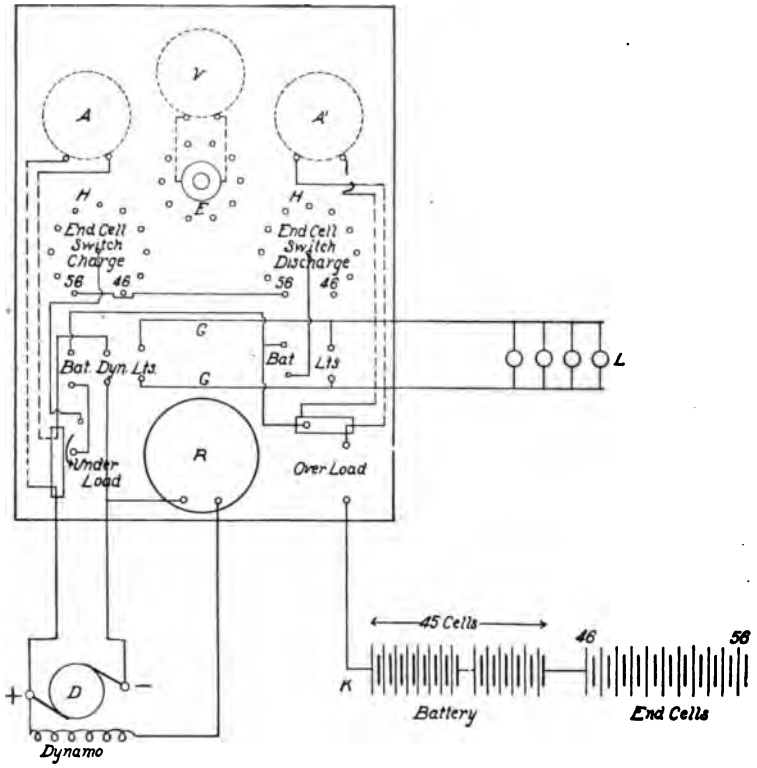


Fig. 24. Switchboard, Dynamo and Battery Connections.

a three-way switch, which enables it to be connected to the dynamo, battery, or lamps respectively.

An automatic overload switch must be inserted in the battery circuit so as to open or introduce resistance into the circuit when the current becomes excessive. An automatic cut-out is required between the dynamo and the battery to open the circuit when the charging current falls below a certain value, and thus avoid any danger of the battery discharging through the dynamo, if from

any cause the E.M.F. of the latter drops below that of the former. This completes the ordinary measuring and circuit-controlling apparatus employed in connection with storage batteries. The arrangement is shown diagrammatically in Fig. 24, in which A and A^1 are the two amperemeters, the third one being omitted in this case; V is the voltmeter; E the voltmeter switch to connect to the dynamo, battery, or lamps as desired; G the bus bars; L, lamps; D, dynamo; R, rheostat in field-circuit of dynamo.

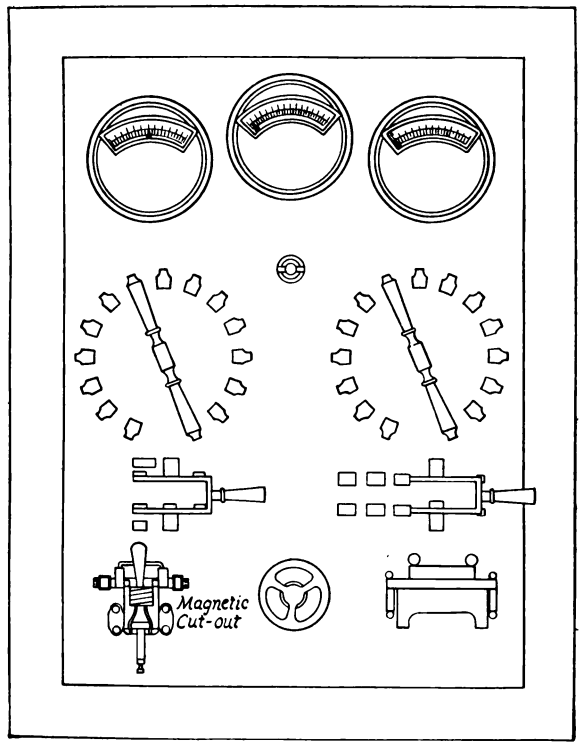


Fig. 25. Face of Switchboard.

The regulating device consists of eleven end cells, which are connected to corresponding contacts on the end cell switches (Fig. 24). But as the drawing of these connections would complicate the figure, they have been omitted. Fig. 25 shows the switchboard with these devices mounted upon it.

The Regulation of Storage Batteries is one of the most

troublesome matters involved in their practical use. This arises from the fact that the voltage falls continually from the beginning to the end of discharge. To be sure, this decline is gradual; but its total value is large, being from about 2.2 to about 1.8 volts, which is a decrease of nearly 18 per cent.

In order to maintain a constant voltage, the usual plan is to have a number of extra cells, which are successively switched into circuit as the potential falls. These reserve cells and the switches which control them are represented in Fig. 24.

The contact pieces of these switches must be made in such a way that they do not short-circuit the cells as they pass from one point to the next. This is accomplished by splitting the movable contact arm into two parts, between which a certain amount of resistance is introduced, so that when the two parts happen to rest on two adjacent contact points, the resistance prevents the cell which is connected to these two points from being short-circuited, and also avoids breaking the circuit.

The number of extra cells depends upon the conditions; for 110 volt lamps, it would require 51 cells to obtain 112.2 volts when fully charged and giving 2.2 volts each, assuming the drop on the conductors at 2 per cent. When the battery becomes discharged, and its potential falls to 1.8 volts per element, 10 additional cells or 61 in all, would be needed. These would yield 111.8 volts, assuming the average potential of the reserve cells to be 2 volts, since they have not been discharged to the same extent as the original battery. If the drop on the conductors is 10 per cent of the lamp voltage, the potential at the battery will have to be $110 + 11 = 121$. This will necessitate 4 more elements, or a total of 65 when the 51 original cells are fully discharged to 1.8 volts, and the 14 extra cells give 2 volts each.

For a three wire system the above figures should, of course, be doubled. This switching of extra cells into and out of the circuit obviously results in discharging them unequally, hence they require to be charged to a corresponding extent. This is accomplished by successively cutting the cells out of circuit as soon as they become fully charged, the last cell which was put into the circuit being fully charged in the shortest time, and so on. The amount of charge is determined by the methods already

given. If the cells employed are not injured by overcharging, they may be left in circuit until the entire battery is fully charged. This saves the trouble of operating the switch; but it is wasteful of energy, since the full counter E. M. F. and resistance of the charged cells must be overcome, which requires about 2.5 volts more per element. The switches might be operated automatically by a voltage regulator or by clockwork.

REGULATION OF GENERATOR IN CHARGING STORAGE BATTERIES.

The variation in E. M. F. which occurs in accumulators renders it somewhat difficult to regulate the generators employed to charge them. A constant potential will give a decreasing rate of charge, owing to the gradual rise in counter E. M. F. This is advantageous, in that it enables the cells to receive a larger charge, but the increase in their voltage is so great that it is practically necessary to regulate the charging potential. In practice it is customary to maintain the charging current approximately constant for considerable periods of time, otherwise it would be difficult to determine the quantity of energy put into the battery, and its efficiency. When extra cells are used they facilitate the regulation of the generator, since they are gradually cut out as the E. M. F. rises.

If the lamps are supplied at the same time that the battery is being charged, some provision must be made for the fact that it may be necessary for the voltage of the dynamo to be considerably higher than that required by the lamps. One plan is to have two separate switches connected to the reserve cells, as shown in Fig. 24, the charging current from the dynamo being led in through one, and the current for the lamps passing out through the other, so that the potential can be independently controlled in the two circuits. Another method is to insert counter E. M. F. cells (without active material) in the circuit between the dynamo and the lamps, in order to bring down the voltage of the former to suit the latter. The number of these cells is varied in accordance with the excess of the potential of the dynamo.

Simple resistance coils may be used in place of the counter E. M. F. cells to reduce the pressure; but the cells have the great advantage, that they have an effect practically independent of

variations in the current. All of these methods, however, involve a waste of power, the value of which in watts is the product of the current in amperes, and the number of volts by which the potential is cut down. In small plants this loss is not serious, but in large plants or central stations it may become very considerable.

Booster Methods of Regulation. The best plan is to make use of a "booster;" in which case the main dynamos are run at the proper voltage to supply the lamps directly, and the additional pressure required to charge the battery is furnished by the booster. This is connected in series with the dynamo, being inserted in the circuit between the latter and the battery.

When a battery is placed at the end of a long feeder to compensate for line drop, and at light loads to act as a storage reservoir it is not usual to equip this "floating battery" with any regulating device. In such cases the battery is simply connected across the line, and the charge and discharge are determined by the feeder drop. For instance, when a small load is on the line, the drop is small, and the potential applied across the battery terminals is high enough to send a charging current into the battery, if the load on the line increases the drop naturally increases, the pressure at the end of the line falls, and if it falls below the battery voltage, the battery discharges in parallel with the generator, and carries a certain portion of the load. The "floating battery" has the advantage of simplicity, and acts immediately, as it has no time lag which is always present in any apparatus depending upon changes in magnetization. Usually the variations in voltage and the fluctuations in load are too great for successful operation of a floating battery on any but an electric railway or power circuit, and a booster would be required if incandescent lighting be a part of the load.

The duty of a booster is to vary the voltage at the battery terminals with variation in load, causing charging or discharging of current as conditions may require. The booster is an auxiliary dynamo, the E. M. F. of which is used to raise or lower the voltage in the battery circuit. These machines are classified as series, shunt, compound, differential and constant current boosters.

The Shunt Booster is a shunt dynamo, driven by any source

of power, having its armature circuit in series with the line from generator to battery. This form is used in plants, where the bat-

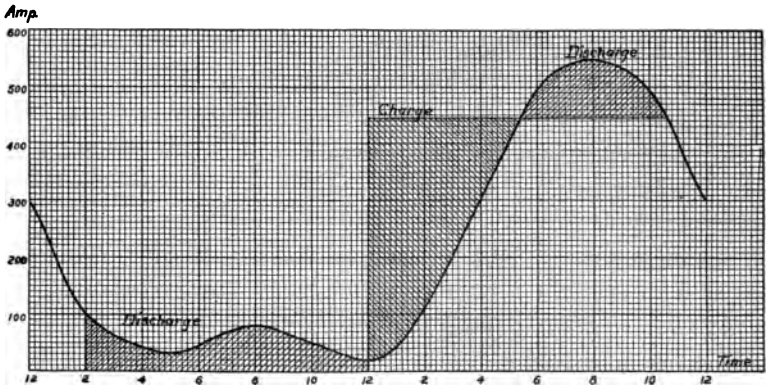


Fig. 26. Load Diagram of Case where Shunt Booster is Applicable.

tery is not designed to take up load fluctuations, but is in service only to carry the peak of the load, being charged during periods of light load, and discharged in parallel with the generator. It acts to increase the voltage applied to the battery so that the

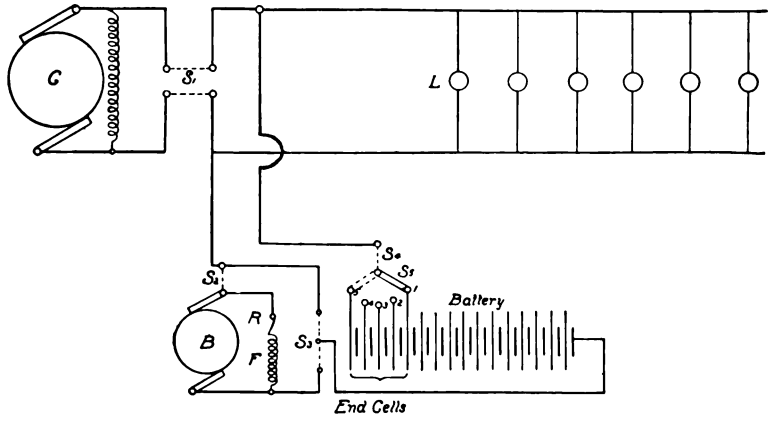


Fig. 27. Diagram of Shunt Booster Connections.

charging current will flow into the latter. As a rule the battery used in conjunction with a shunt booster is made large enough to carry the entire load during the light load period. As the battery discharges and its voltage drops, the "end cells" (regulation cells)

are cut in and the proper voltage maintained. Fig. 26 shows a load diagram to which this system is applicable, and Fig. 27 shows diagramatically the connections of this system. A rheostat is used to vary the booster voltage, so as to hasten the charging of the battery if desired. It is to be noted that the shunt booster is not applicable where there are sudden fluctuations that are great compared with the capacity of the generator, and that it is not automatic in changing from charge to discharge, the switching being performed by hand.

Series Booster. The connections are like those of the shunt booster with the battery and booster in series across the line but the field of the booster being in series with the battery circuit, its E. M. F. is zero when no current is flowing in or out of the battery. Should the voltage of the line rise, due to a decrease of load, and a charging current flow into the battery, the E. M. F. of the booster would increase, and thus tend to increase the rate of charge. The reverse occurs when the battery discharges, as an increase of load on the line increases the current through the series field of the booster, thus raising the voltage of discharge so that the battery carries a larger part of the load.

This booster acts to compound the battery on discharge, and tends to maintain a constant voltage on the line. It depends on the fact that the generator voltage falls when the load increases; hence it is used with a shunt generator or equivalent source of supply.

This system is applicable to power but not to lighting purposes, and is similar in its operation to a "floating battery." It is not as extensively used as the compound and differential booster arrangements which give better regulation under similar conditions.

Compound Booster. This system is used on railway and power curcuits with great fluctuations in load, the battery acting to prevent excessive drop and to assist the generating machinery in carrying the load, relieving it from the strain of sudden rushes of current. The connections of this system are indicated in Fig. 28, and the operation is as follows: — Under normal load conditions the shunt field Fh of the booster creates an E. M. F. in the same direction as the battery, tending to discharge it. Calling E_g the

generator E. M. F. E_g, the booster E. M. F. and E_b the battery E. M. F., we have $E_g - E_a = E_b$ when no current is flowing into or out of the battery. In this case the generator carries the whole external load.

If the load increases E_g decreases, so that $E_b - E_a$ is greater than E_g, and the battery begins to discharge. In discharging, the current passes through the series field Fs of the booster and produces a proportional E. M. F., acting with the shunt field to raise

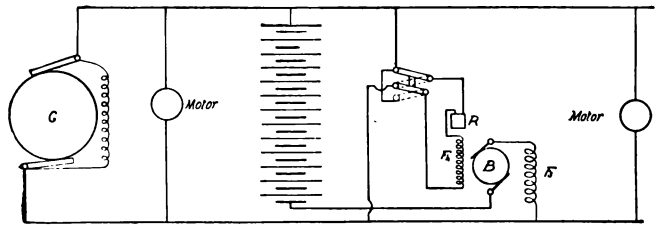


Fig. 28. Diagram of Compound Booster Connections.

E_a, thus increasing the battery discharge and shifting more of the load from the generator, until the system becomes balanced.

If the load on the external circuit be light, the generator voltage E_g rises and current flows into the battery. In this case the series field acts against the shunt field and decreases E_a, so that the generator voltage is greater than booster and battery voltage combined, thus increasing the rate of charge of the battery, until the load causes the generator voltage to drop to normal and the system is again balanced. The battery and booster can be placed at the power house or at the point at which the greatest drop is likely to occur.

A battery can also be used to help out the generators at the peak of the load, by increasing the shunt field current and thus causing $E_a - E_b$ to be greater than E_g.

Since this system also depends for its action upon the drop of voltage with increase of load, it is only applicable to shunt wound generators or equivalent source.

Differential Boosters. The differential booster system most commonly used, is shown in Fig. 29.

The compensating field S_1 prevents the variation of the battery E. M. F. from disturbing the equilibrium of the system. If

the battery E. M. F. be lower than normal it will not discharge rapidly enough to relieve the generator from overload fluctuations, unless the booster E. M. F. be increased, and the generator will therefore have to supply a current of greater than its normal value. If however a current of greater value than the normal flows through S_1, the value of (f–S_1) is decreased, and S_2 still further overpowers the resultant of (f–S_1) and causes a higher booster E. M. F. tending to discharge the battery, and thus brings down the generator load to normal. Should the battery E. M. F. be above

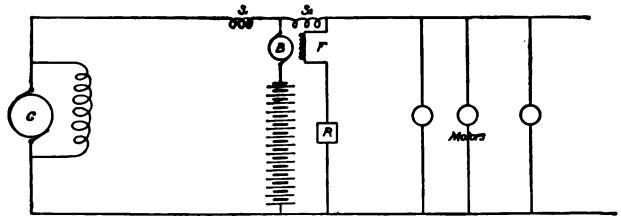


Fig. 29. Diagram of Differential Booster Connections.

its normal value, the battery would discharge too rapidly and carry more than its share of the load; in this case (f–S_1) is greater than it should be, and the booster E. M. F. causes the load to become evenly distributed between the battery and generator.

In operating this system the varying load must be beyond the booster equipment. If desired the coils S_1 and S_2 may be short circuited so that the battery may be charged more rapidly.

Constant Current Booster. In systems having short lines and small drop it is often desirable to have the voltage fall on sudden application of an overload, so that the rush of excessive current is prevented. This rush of current occurs in buildings where elevator and power motors constitute a large percentage of the load, and to prevent it, the constant current booster system is used.

Fig. 30 represents a constant current booster system, in which the main current passes through the armature and series field of the booster, and this current does not reverse.

The voltage impressed on a fluctuating load of motors on the right, is greater than that impressed on a non-fluctuating load of lamps on the left, by the amount of the booster voltage.

The shunt coil f creates an E. M. F. in the same direction as the generator E. M. F., while the series coil F opposes it.

Should a load come in the motor portion of the circuit, the generator sends a greater current through the series coil S, the action of which reduces the booster E. M. F. in direct proportion to this rush of current, and causes the booster E. M. F. to vary inversely as the motor load, thus tending to maintain an almost constant current delivery from generator. If it is desired to have

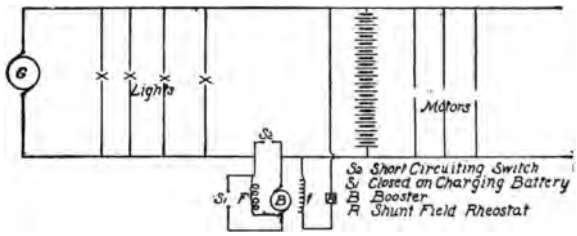


Fig. 30. Diagram of Constant Current Booster Connections.

the battery furnish power to both the lights and motors, at periods of light load, and not use the generator, this can be done by simply opening generator switch and short circuiting the booster by closing switch S_2.

The switch S_1 is closed in charging the battery, as the rate of charge can be controlled by varying the shunt field resistance R. This is often done, when the battery has been carrying a heavy load for some time and the recharging must be hurried.

The shunt coil f creates an E. M. F. in the same direction as the generator E. M. F., while the series coil F opposes it.

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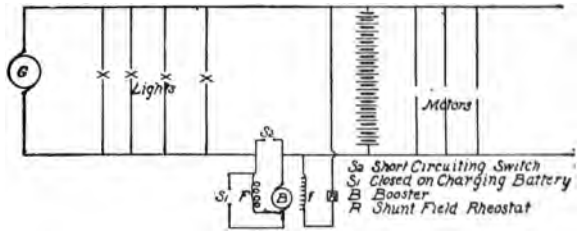

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EXAMINATION QUESTIONS.

THE FOLLOWING LISTS OF QUESTIONS AFFORD THE READER A MEANS OF TESTING HIS KNOWLEDGE OF THE SUBJECTS TREATED IN THE PRESENT VOLUME. ANYONE WHO HAS CAREFULLY READ THE FOREGOING SUBJECTS SHOULD BE ABLE TO ANSWER EVERY QUESTION CORRECTLY. THE READER IS ADVISED TO GO THROUGH THE QUESTIONS CAREFULLY, WORKING OUT HIS ANSWERS AND CHECKING HIS RESULTS WITH THE ANSWERS GIVEN. THIS WILL AFFORD A VALUABLE MEANS OF FIXING THE MATTER IN MIND. STUDENTS WHO ARE PREPARING FOR EXAMINATIONS FOR COLLEGE OR CIVIL SERVICE WILL FIND THE QUESTIONS OF THE GREATEST VALUE.

THE ELECTRIC CURRENT.

Instructions to the Student. Place your name and full address at the head of the paper. Work out in full the examples and problems, showing each step in the work. Mark your answers plainly "Ans." Avoid crowding your work as it leads to errors and shows bad taste. Any cheap, light paper like the sample previously sent you may be used. After completing the work add and sign the following statement.

I hereby certify that the above work is entirely my own.

(Signed)

1. (*a*) Explain what is meant by electromotive force. (*b*) What is its unit of measurement, and by what value is it represented?

2. (*a*) What is necessary to cause an electric current to flow? (*b*) What is meant by the strength of a current? (*c*) What is its unit of measurement, and by what value is it represented?

3. What is the unit of resistance and by what value is it represented?

4. Upon what three general factors does resistance depend?

5. What length of copper wire 2 millimeters in diameter will have the same resistance as 12 yards, 1 millimeter in diameter?

Ans. 48 yards.

6. State Ohm's law.

7. Two wires, whose resistances are respectively 28 and 24 ohms, are placed in parallel in a circuit so that the current divides, part passing through each. What resistance is offered by them to the current? Ans. 12.92 + ohms.

8. Fifty Grove's cells (E. M. F. = 1.8 volts) are in series, and united by a wire of 15 ohms resistance. If the internal resistance of each cell is .3 ohm, what is the current? Ans. 3 amperes.

9. (*a*) What is the unit of quantity of electricity? (*b*) Define the ampere-hour.

10. What is the power in watts when 4000 joules of work are done in 50 minutes? Ans. 1.33 + watts.

11. How many horse-power are equivalent to 83 kilowatts?

Ans. 111 + horse-power.

by the sulphur, will it be attracted or repelled by the ivory, and why?

19. What is an electroscope?

20. Explain how polarization is overcome in double fluid cells.

21. How may it be shown that the field of a magnet exerts its influence in certain definite directions?

22. What are the essential parts of a condenser?

23. How may it be shown that the charge upon a body resides upon its surface?

24. What is meant by the terms "primary coil" and "secondary coil"?

25. How does the method of "forming" the plates of a Planté cell differ from that of "forming" plates of the Faure type?

26. Why does attraction take place between a charged body and a conductor brought within its inductive influence?

27. In what manner does polarization decrease the power of a cell?

28. State three ways in which a current may be induced in a coil of wire.

29. What is meant by electrolysis? What is an electrolyte? An anode? A kathode?

30. Upon what main factors does the amount of charge induced by a charged body upon a conducting body depend?

31. State Joule's law.

32. How may it be shown that a wire carrying a current is surrounded by a magnetic field?

33. (*a*) When glass is rubbed by wool, which substance receives a positive charge, and which one a negative charge? (*b*) Does the charge produced on the glass exceed in quantity that produced on the wool?

34. Why is it possible to obtain very high electromotive forces by means of the induction coil?

35. Explain why there is no gain in energy by use of the electrophorus without a corresponding expenditure of work.

THE ELECTRIC CURRENT.

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Ans. 48 yards.

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11. How many horse-power are equivalent to 83 kilowatts?

Ans. 111 + horse-power.

12. What is a shunt circuit?

13. A current of 18 amperes flows in a circuit whose resistance is 116 ohms. What is the voltage? Ans. 2088 volts.

14. The resistance of 312 feet of a certain wire is 2.08 ohms. What would be the resistance of 240 feet of the same wire? Ans. 1.6 ohms.

15. A total current of 56 amperes passes through a divided circuit having the resistance of its branches equal to 28 and 4 ohms respectively. What is the current in each branch?

Ans. In the 28-ohm branch, 7 amperes.
In the 4-ohm branch, 49 amperes.

16. What is the value of the current when 4 ampere-hours are delivered in a circuit in 20 minutes? Ans. 12 amperes.

17. (*a*) Define the joule. (*b*) Define the watt.

18. A 220-volt circuit supplies a current of 18 amperes. What is the power in kilowatts? Ans. 3.96 K. W.

19. If the resistance of a certain wire is 2.3 ohms per 1000 feet, how many feet of the wire will be required to make up a resistance of 17.8 ohms? Ans. 7739 + feet.

20. What is the resistance of a wire having a diameter of .2 inch if the resistance of the same length of similar wire having a diameter of .04 inch is 64.2 ohms? Ans. 2.56 + ohms.

21. Define specific resistance.

22. The resistance of a circuit is 1.8 ohms and the voltage is 110. What is the current? Ans. 61 + amperes.

23. A circuit contains a voltaic cell generating an electromotive force of 1 volt. Its electrodes are connected by three wires in parallel of 2, 3, and 4 ohms resistance respectively. The resistance of the cell is $\frac{1}{13}$ ohm. What is the current?

Ans. 1 ampere.

24. Eight cells each having an E. M. F. of .9 volt and an internal resistance of .6 ohm are connected in parallel, and the external resistance is 3.4 ohms. Find the current.

Ans. .26 ampere (approx.).

25. What quantity of electricity will be conveyed by a current of 40 amperes in half an hour? Ans. 72,000 coulombs.

26. The resistance of a circuit is 10 ohms, and the current is 33 amperes. What is the power in watts? Ans. 10,890 watts.

27. How many watts are equivalent to 14 horse-power?
Ans. 10,444 watts.

28. Five conductors having resistances respectively equal to 14, 3, 20, 31 and 8 ohms are joined in series, and the E. M. F. applied to the circuit is 50 volts. What is the current?
Ans. .65 amperes.

29. (*a*) Define conductance. (*b*) Define conductivity.

30. What is the resistance of 10 feet of annealed gold wire .001 inch in diameter at 32° F., if the resistance of an inch cube of the substance at 32° F. is .8079 microhm? Ans. 123 + ohms.

31. A copper wire has a resistance of 13.5 ohms at 43° F. What is its resistance at 57° F? Ans. 13.91 + or nearly 14 ohms.

32. What must be the resistance of a 220-volt circuit if the current is to be 70 amperes? Ans. 3.14 + ohms.

33. The E. M. F. applied to a circuit is 582, and the current is 8 amperes. A number of lamps connected in the circuit require a total drop of 522 volts. Find the resistance of the remaining portion of the circuit. Ans. 7.5 ohms.

34. A circuit is made up of six wires connected in parallel and having resistances of 72, 60, 21, 36, 40 and 210 ohms respectively. Find their joint resistance. Ans. 7.3 + ohms.

35. When a cell, which has an internal resistance of 1.39 ohms and an E. M. F. on open circuit of 1.32 volts, is supplying a current of .29 ampere, what is its available E. M. F.?
Ans. .92 volts (approx.).

36. With a current of 20 amperes how much time will be required to deliver 4,000 coulombs. Ans. 3 minutes, 20 seconds.

37. The voltage of a circuit is 103 and the current is .5 ampere. What energy is expended in a minute and a half?
Ans. 4635 joules.

38. The resistance of a coil of platinoid wire at 98° C. is 3014 ohms. What resistance would the coil have at 18° C.?
Ans. 2962 ohms (approx.).

39. What is the resistance of 28 feet of No. 6 (B. & S.) pure copper wire at 90° F.? Ans. .0118 + ohm.

40. If a resistance of 116 ohms be inserted in a circuit, and it is desired to maintain a constant current of 9.6 amperes, how much must the voltage of the circuit be increased?
Ans. 1113 + volts.

41. When a current of 14 amperes flows in a circuit whose resistance is 54 ohms, what energy in kilowatt-hours is expended in half an hour? Ans. 5.292 kilowatt-hours.

42. Explain the difference between the kilowatt and the kilowatt-hour.

43. What number of calories will be developed by a current of .14 ampere flowing through a wire of 4 ohms resistance for 5 minutes? Ans. 5.6 + calories.

44. The voltage applied to a circuit in which three wires are connected in parallel is 107. Find the current in each branch if the separate resistances are respectively 43, 9 and 25 ohms.

Ans. In 43-ohm branch, 2.4 + amperes.
In 9-ohm branch, 11 + amperes.
In 25-ohm branch, 4.2 + amperes.

45. How many horse-power are equivalent to 1048 watts?

Ans. 1.4 + horse-power.

46. If the resistance of 1 foot of annealed silver wire .001 inch in diameter at 32° F. is approximately 9.02 ohms, what is the resistance of 4 miles of the wire .01 inch in diameter at a temperature of 90° F.? Ans. 2137 + ohms.

47. Twenty large Leclanche cells (E. M. F. = 1.5 volts, resistance = 0.5 ohm each) are in a circuit in which the external resistance is 10 ohms. Find the strength of current which flows (*a*) when the cells are joined in series; (*b*) when all the cells are in parallel; (*c*) when there are 2 files each having 10 cells in series; and (*d*) when there are 4 files each having 5 cells in series.

Ans. Amperes (*a*) 1.5; (*b*) 0.149; (*c*) 1.2; (*d*) 0.706.

48. How many kilowatts are equivalent to 150 horse-power?

Ans. 111.9 K. W.

49. If a current of 9.3 amperes flows when the voltage of a circuit is 110, how much resistance must be inserted in the circuit to reduce the current to 3.4 amperes? Ans. 20 + ohms (approx.).

50. A current of 26 amperes is flowing in a circuit which has a voltage of 500. What is the equivalent power in mechanical units? Ans. 17.4 + horse-power.

ELECTRIC WIRING.

READ CAREFULLY: Place your name and full address at the head of the paper. Any cheap, light paper like the sample previously sent you may be used. Do not crowd your work, but arrange it neatly and legibly. *Do not copy the answers from the Instruction Paper; use your own words, so that we may be sure that you understand the subject.*

1. Under what conditions is "fishing" of wires allowed? Explain the process.

2. In conduit work how many quarter bends are allowed from outlet to outlet?

3. Tell what you can about flexible cord.

4. Where should cut-outs or circuit breakers be located for house wiring?

5. What must be the voltage of the dynamo in order to supply lamps or motors in a 110-volt system, with a 5 per cent loss?

6. What is a cull pole?

7. When a high-potential machine has its frame grounded, what precautions should be taken for the protection of the attendant?

8. What can you say about the rules to be followed when installing wires?

9. Give a rule for the proper depth to which to set a pole.

10. How would you ground a dynamo frame?

11. What is the least allowable radius of curvature in conduit work?

12. State the rule to be followed in starting or stopping motors.

13. What is the objection to putting the ground wire from a lightning arrester into an iron pipe?

14. State briefly the requirements for interior wiring in the case of series arc lighting work.

15. Describe the care which should be given to the brushes to keep them in good condition.

16. Describe a piece of apparatus for protecting the armature of a motor.

17. Why should standard rubber-covered wires be used in conduit work?

18. What is the least space that should be left between
(a) The switchboard and the floor?
(b) The switchboard and the ceiling?

19. What is the largest permissible current dependent upon one cut-out?

20. What insulation resistance is required between gas pipe attachments and an insulating joint?

21. Under what conditions should the frame of a dynamo be grounded?

22. What kind of wire must be used in moulding work?

23. What can you say about wiring for damp places?

24. In which direction does the armature of a generator usually revolve?

25. Determine by use of table on page 40 what size of wire should be used to supply 75 16-candle-power incandescent lights, 110 volts, loss 3 volts, and at a distance of 200 feet to center of distribution.

26. What is the best material for poles?

27. Describe a method of setting the brushes so that they will be diametrically opposite each other.

28. In splicing two pieces of wire, what precautions are necessary?

29. What size of wire will be required to supply a 10-horse-power motor on a 500-volt circuit at a distance of 200 feet with 15 volts' drop?

30. What current is taken by the motor referred to in Question 29?

31. Describe the connections for the three-wire system.

32. Determine by formula the size of wire for 40 16-candle-power incandescent lights on a 110-volt circuit with 5 volts' drop at a distance of 150 feet.

STORAGE BATTERIES.

Read carefully: Place your name and full address at the head of the paper. Any cheap light paper like the sample previously sent you may be used. Do not crowd your work, but arrange it neatly and legibly. *Do not copy the answers from the Instruction Paper: use your own words, so that we may be sure that you understand the subject.* After completing the work add and sign the following statement:

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(Signed)

1. What is the lowest voltage to which a lead battery should be discharged?

2. What means may be employed to make up for the drop in potential of storage batteries during discharge?

3. What causes sulphating?

4. What plate of a storage battery is the positive?

5. Describe the several indications by which the amount of charge in a storage battery can be determined.

6. How is the capacity of a storage battery usually expressed?

7. What is an electrolyte?

8. What is meant by a floating battery, and when it is applicable?

9. How must a storage battery room be arranged?

10. What causes buckling?

11. Why are there always more negative plates than positive plates in a storage battery?

12. Give several applications of storage batteries.

13. When a storage battery is charged what is found on the positive plate and what is found on the negative plate, and what occurs when the cell is discharged?

14. What is the maximum voltage obtainable from a lead storage cell?

15. How may sulphating and buckling be prevented?

16. How would you put a battery out of commission for a long period, and how would you place it in service again?

17. What is the difference in construction between Faure and Planté plates?

18. What is the essential difference between a primary and storage battery?

19. What instruments are required on a storage battery switchboard, and how are they connected?

20. If a battery be discharged at a greater rate than its normal, how does it temporarily affect the capacity of the cell?

21. What impurities in the electrolyte must be guarded against, how is their presence caused, and how determined?

22. Which type of cell has the larger storage capacity per lb. of cell, and why; the Faure or Planté?

23. Why is the storage battery useful in electrical laboratories?

24. What is the specific gravity of the electrolyte of a lead cell when fully charged, and about what when discharged?

25. What is the constant current booster system, and where is it most applicable?

THE FOLLOWING PAGES ARE TAKEN FROM THE BULLETIN OF THE AMERICAN SCHOOL OF CORRESPONDENCE AT ARMOUR INSTITUTE OF TECHNOLOGY, CHICAGO.

OTHER COURSES OFFERED ARE ARCHITECTURE; CIVIL, MECHANICAL, STATIONARY, LOCOMOTIVE AND MARINE ENGINEERING; HEATING, VENTILATION AND PLUMBING; SHEET METAL PATTERN DRAFTING; MECHANICAL AND PERSPECTIVE DRAWING; REFRIGERATION; TELEPHONY; TELEGRAPHY; AND TEXTILES, INCLUDING THE MANUFACTURE OF COTTON AND WOOLEN CLOTH, TEXTILE DESIGN, AND KNITTING; ALSO COLLEGE PREPARATORY COURSES FOR ENGINEERING COLLEGES.

COMPLETE BULLETIN OF 200 PAGES GIVING COMPLETE SYNOPSIS OF ABOVE COURSES MAY BE HAD ON REQUEST.

Main Building, Armour Institute of Technology.

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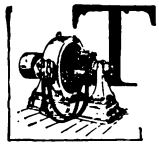
DEPARTMENT OF

ELECTRICAL ENGINEERING

COURSES

ELECTRICAL ENGINEERING
MECHANICAL-ELECTRICAL ENGINEERING
CENTRAL STATION WORK
ELECTRIC LIGHTING
ELECTRIC RAILWAYS
TELEPHONE PRACTICE
THE ELECTRIC TELEGRAPH
ELECTRIC WIRING

ELECTRICAL ENGINEERING



THE rapid development of Electrical Engineering during the last few years has been due largely to a recognition of the real importance of theory. Success in practical work is attained only by the application of sound theory. The courses in this department aim to give thorough instruction concerning the most essential of these theories and their practical applications to the industrial arts.

The student first lays a foundation by taking the preliminary studies which are elementary in character and treated as briefly as the technical work will permit. The technical portion includes instruction in batteries, Ohm's law, induction, etc. Both direct and alternating current machines are discussed in detail and many suggestions given for their practical management; the application of electricity to lighting, bell-work, railways, central station work, telephones and telegraph are taken up in a manner suited to the practical man as well as to the student.

The methods of testing with instructions for using measuring instruments make the various problems easily understood. Among the interesting features of the course may be mentioned, storage-battery work, practical directions for wiring houses for electric bells, electric lights, burglar alarms, gas lighters, etc. To make the work more complete, especially for those engaged in central station work, instruction is given in steam boilers, pumps and engines.

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ELECTRICAL ENGINEERING COURSE

INCLUDING MECHANICAL DRAWING

Prepared for Electricians, Electrical Engineers, Power Station Engineers, Motormen, Automobile Drivers, Dynamo Tenders, Testers, Linemen, Designers, Draftsmen, Telegraph Operators, Telephone Inspectors, Lamp Trimmers, Inventors, Chemists, Patent Lawyers, Instructors, Students, Dealers in Electrical Machinery, and others.

INSTRUCTION PAPERS IN THE COURSE

Arithmetic Part I.
Arithmetic Part II.
Arithmetic Part III.
Elementary Algebra and Mensuration.
Mechanics Part I.
Mechanics Part II.
Mechanism.
Heat.
Elements of Chemistry.
Metallurgy.
Elements of Electricity.
The Electric Current.
Machine Design Part I.
Machine Design Part II.
Theory of Dynamo-Electric Machinery.
Direct Current Dynamos.
Direct Current Motors.
Types of Dynamo-Electric Machinery.
Management of Dynamo-Electric Machinery.
Storage Batteries.
Types of Boilers.
Boiler Accessories.
Steam Pumps.
Steam Engine Part I.
*Steam Engine Part II.
Electric Wiring.
Electric Lighting.
Electric Railways.
Algebra Part I.
Algebra Part II.
Geometry.
*Trigonometry and Logarithms.
Electrical Measurements.
Alternating Current Machinery Part I.
Alternating Current Machinery Part II.
Central Stations and Power Transmission.
Design of Direct Current Dynamos.
*The Electric Telegraph.
*The Telephone.
Mechanical Drawing Part I.
Mechanical Drawing Part II.
Mechanical Drawing Part III.
Mechanical Drawing Part IV.
*Mechanical Drawing Part V.
*Mechanical Drawing Part VI.

The student may take either the Electric Telegraph or the Telephone.

*Optional.

NOTE: The Instruction Papers prepared by **Prof. Wm. Esty**, *head of the Department of Electrical Engineering, Lehigh University, on* **Alternating Current Machinery**, *describe the latest machines and their operation and explain the advanced theories without the use of higher mathematics. The papers on* **Management of Dynamo Electric Machinery**, *by* **Prof. F. B. Crocker** *(joint author with S. S. Wheeler of "Practical Management of Dynamos and Motors") give the most recent and best practice on this subject; and in* **Electric Railways**, *prepared by* **James R. Cravath**, *Western Editor "Street Railway Journal," will be found the most recent developments, including elevated railway work, with full treatment of the Third Rail, Multiple Unit, and Alternating Current Systems; Magnetic Brakes, Air Brakes, and Safety Arrangements.*

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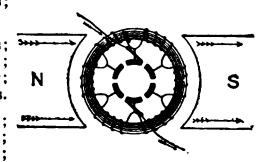
GENERAL STUDIES

ARITHMETIC, ELEMENTARY ALGEBRA AND MENSURATION, MECHANICS, MECHANISM, HEAT, ELEMENTS OF CHEMISTRY, METALLURGY } SEE SYNOPSIS PAGE 166

ELECTRICITY

ELEMENTS OF ELECTRICITY: Magnetism; Magnetic Induction; Static Electricity; Insulators; Conductors; Charges; Electric Machines; Condensers; Dynamic Electricity; E.M.F.; Resistance; Cells; Solenoid; Electro-magnets; Induction Coils; Applications; Telephone; Telegraph.

ELECTRIC CURRENT: Resistance; Conductance; Tables; Calculations; Coefficients; Wire Tables; Ohm's Law; Circuits; Fall of Potential; Electric Energy; Power; Coulomb; Joule; Watt; Mechanical Equivalent; Plants.

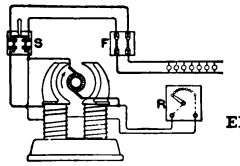


THEORY OF DYNAMO-ELECTRIC MACHINERY: Symbols; Lines of Force; Induction; The Generator; Commutator; Permeability; Saturation; Hysteresis; Armature Reaction; Neutral Point; Lead; Demagnetization; Types of Fields; Series, Shunt and Compound Windings.

DIRECT CURRENT DYNAMOS: Constant Current; Constant Potential; Characteristic Curves; External; Internal; Total. Long and Short Shunts. Magneto-motive Force; Magnetic Reluctance; Magnetizing Force. Field Magnets. Dynamo Construction: Armature; Armature Core and Windings; Binding Wires; Closed and Open Coil Armature Commutators; Brushes; Brush Holders; Field Magnets and Coils. Sparking. Installation. Operation. Testing.

DIRECT CURRENT MOTORS: Principles; Equations: Counter E. M. F.; Torque and Speed; The Prony Brake; Shunt and Series Motors; Compound Motor; Series Motor; Regulation; Transformers; Generator and Motor in Combination; Calculations.

TYPES OF DYNAMO-ELECTRIC MACHINERY. DIRECT CURRENT. Classes; Methods of Driving; Types: General Electric; Crocker-Wheeler; Westinghouse; Bullock; C and C; Holtzer-Cabot, etc.: Electrolytic Work; Arc Lighting Generators; Railway Motors; Motor-Generators and Dyna-motors.



MANAGEMENT OF DYNAMO-ELECTRIC MACHINERY: Selection; Erection; Connection; Operation; Construction; Handling; Regulation; Foundations; Installation; Belts; Assembling; Wiring; Circuit Breakers; Circuits; Starting; Stopping; Generators in Parallel; Generators in Series; Three-wire System; Inspecting; Testing; Detection and Remedy of Troubles; Sparking; Heating; Noise; Railway Motors.

ELECTRIC WIRING: Wires; Coverings; Joints; Wiring Fixtures; Cleats; Casings; Tunnels; Switches; Plugs; Sockets; Fuses; Meters; Applications; Plans and Specifications; Fire Risks; Insurance Rules and Regulations; Inspectors.

STORAGE BATTERIES: Plante; Faure; Forming Plates; Setting up; Electrolyte; Tests; Discharging; Efficiency; Sulphating; Buckling; Disintegrating; Short Circuiting; Over Discharging; Uses; Connections; Diagrams; Switches; Regulation of Charging Generator; Boosters.

ELECTRIC LIGHTING: Lamps; Candle Power; Incandescent Lamps; Arc Lights; Systems of Distribution, Feeders; Potential; Location of Lamps; Power Required; Location and Equipment of Plant; Overhead and Underground Systems; Wiring of Buildings; Size of Wire; Calculations.

ELECTRIC RAILWAYS: Car Equipment; Armature Coils, Loads and Brushes. Inspection; Gearing; Lubrication; Bearings; Motor Suspension; Controllers and Car Wiring; Series Parallel Control; Rheostat Control; Controller Construction and Wiring; Magnetic Blow-out; Multiple Unit System; Car Heaters; Car Wiring; Resistances; Car Accessories; Trucks; Brakes; Air Brake; Magnetic Brake; Car Bodies; Overhead Construction; Trolley Wire; Feeders; High-Tension Lines; Third Rail; Conduit System; Track Construction; Joints; Bonding and Return Circuits; Electrolysis; Power Supply and Distribution; Alternating Current Transmission; Power Station; Switch Boards; Alternating Current Systems; Operation; Testing; Faults.

ELECTRICAL MEASUREMENTS: Units, Symbols for Physical Quantities. Galvanometers; Rheostats; Voltmeters; Ammeters; Wattmeters; Measurement of Resistance. Locating Faults; E. M. F. of Alternating Currents. Calibration of Voltmeters and Ammeters. Measurement of Energy, Quantity and Capacity.

ALTERNATING-CURRENT MACHINERY: Simple Alternator; Alternating E. M. F. and Current; Armature Cores and Windings; Cycle; Graphical Representation; Average Values; Effective Values; Form Factor; Instantaneous and Average Power; Harmonic E. M. F. and Current; Definitions; Synchronism and Phase Difference; Maximum and Effective Values; Expression for Power; Inductance; Capacity; Reactance; Impedance; Fundamental Equation; Resonance; Measuring Instruments; Measurement of Power; Armature Reaction; Alternator Regulation; Excitation; Single Phase Alternator; Polyphase Alternator; Armature Winding; Types; Losses; Efficiencies; Ratings; Tests; Synchronous Motor; Transformer; Transformer Connections; Regulation; Types; Tests. Rotary Converter; Power Ratings; Induction Motor; Stator Winding; Motor Generator; Switch Boards and Station Appliances.

CENTRAL STATIONS: Location; Buildings; Machinery; Measuring Instruments; Switchboard; Starting; Stopping; Faults in Generators and Motors; Accumulators; Charging and Discharging; Troubles. Power Transmission: Line Loss; Direct and Alternating Current Systems; Voltages; Wiring; Transmission Lines; Losses; Illustrative Installations.

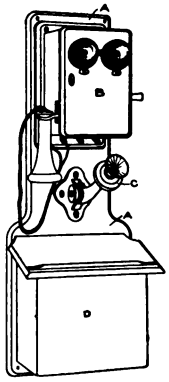
TELEPHONE PRACTICE

A complete, practical course for all those engaged in Telephone Work.

INSTRUCTION PAPERS IN THE COURSE

Arithmetic Part I.
Arithmetic Part II.
Arithmetic Part III.
Elementary Algebra and Mensuration.
*Heat.
*Elements of Chemistry.
Elements of Electricity.
The Electric Current.
*Theory of Dynamo-Electric Machinery.
Types of Dynamo-Electric Machinery.
Electrical Measurements.
Telephony Part I.
Telephony Part II.
Telephony Part III.
Telephony Part IV.
Telephony Part V.

*Optional.



TELEPHONY

SOUND AND ELECTRICITY: Electrical Energy, Batteries, Primary and Secondary Alternating Currents, Magnetism, Induction, Dynamos, Electro-Static Capacity.

HISTORY: Bell Receiver, Microphone, Early Transmitters, Modern Forms, Hunnings-Hughes, Berliner, Blake, Solid Back.

TELEPHONE INSTRUMENTS: For Talking, Signalling, Bells, Generators, Complete Telephone—Bridging and Series.

TELEPHONE LINES: Arrangement, Metallic and Grounded Circuits, Distribution in Outline, Trunk Lines, Toll Lines, Subscriber Lines.

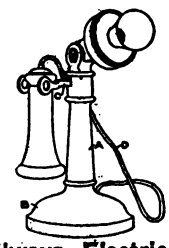
LINE CONSTRUCTION: Classification, Open Wire Lines, Materials of Construction, Poles, Pole Fittings, Cross Arms, Erection of Poles, Stringing Wire, Guying, Aerial Cable Lines, Stringing Suspension Wire, Suspension Cable, Cable Cross Arms, Underground Cable Lines, Subways, Manholes, Pulling in Cables, Splicing and Pot Heading, Terminal Points, Test Points, Distributing Points, Submarine Cable Lines.

PROPERTIES: Transmission, Noisy Lines, Heavy Lines, Cross Talk—by Line, by Central Office Apparatus. Remedies. Retardation Coils, Repeating Coils, Transposition, Pupin's Load Coils.

TELEPHONE EXCHANGE: Systems of Operating in Outline, Switchboards, Standard, Multiple, Special, Main Distributing Board, Intermediate Distributing Board, Exchange Wiring, Subscriber and Trunk Circuits, Order Circuits; Office Circuits, Power Apparatus, Primary Batteries, Secondary Batteries, Charging Machine, Ringing Current Machine, Special Machines.

TELEPHONE OPERATING: Operating Force, Operating Systems, Standard Board, Local Calls, Trunk Calls.

TOLL OPERATING: Toll Boards, Toll Lines, Long Distance Switchboards.



TELEPHONE SYSTEMS: Direct Line, Party Line, Code Signalling, Selective Ringing, B. W. C. System, Four Party Systems, Automatic Systems, House Systems, Private Branch Exchanges.

COMMON BATTERY SYSTEM: Theory, Switchboard, Subscriber's Apparatus, Circuits, Auxiliary Apparatus.

TELEPHONE MAINTENANCE: Testing and Clearing Trouble, Wire Chief's Desk, Testing Circuits and Apparatus, Wire Chief's Force, Method of Reporting and Clearing Trouble.

CABLE MAINTENANCE: Testing New Cables, Cutting Into Service, Locating Faults, Replacing Defective Sections.

Also courses on Central Station Work, Electric Railways, Electric Lighting, Electric Wiring, Electric Telegraph, together with courses on Civil, Mechanical, Steam, and Sanitary Engineering—Architecture and Textiles.

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HARRIS C. TROW, S. B.

American School of Correspondence.

JAMES R. CRAVATH

Western Editor "Street Railway Journal."

P15 1 $\frac{.5904}{1,000,000} \times \frac{1080}{.0312} \times = .02+$ ohms

$\frac{9.689 \times 30000}{1,000,000 \times .125} = 2.32$ ohms